Columbia - Theses

State of Connecticut

State Geological and Natural History Survey

BULLETIN No. 46

STANFORD UNIVERSITY LIBRARY
MAR 24 1930

The Physical History of the Connecticut Shoreline

By

HENRY STAATS SHARP, A.M.

Instructor in Geology, Columbia University

Columbia

STANFORD UNIVERSITY LIBRARIES
WITHDRAWN

HARTFORD

PUBLISHED BY THE STATE

1929

3781
C12S

UNCLASSED

Dissertation

State of Connecticut

PUBLIC DOCUMENT No. 47

State Geological and Natural History Survey

W. E. BRITTON, Ph.D., Superintendent

BULLETIN No. 46

HARTFORD

Printed by the State Geological and Natural History Survey

1929

State Geological and Natural History Survey of Connecticut

COMMISSIONERS

JOHN H. TRUMBULL, *Governor of Connecticut*
JAMES ROWLAND ANGELL, *President of Yale University*
JAMES LUKENS MCCONAUGHY, *President of Wesleyan University*
REMSEN BRINCKERHOFF OGILBY, *President of Trinity College*
GEORGE ALLAN WORKS, *President of Connecticut Agricultural College*
IRENE NYE, *Acting President of Connecticut College for Women*

SUPERINTENDENT

W. E. BRITTON, PH.D.
Agricultural Experiment Station, New Haven.

DISTRIBUTION AND EXCHANGE AGENT

GEORGE S. GODARD, *State Library*
Hartford

Publication approved by the Board of Finance and Control

PRESS OF THE WILSON H. LEE COMPANY
NEW HAVEN, CONN.

The Physical History of the Connecticut Shoreline

By

HENRY STAATS SHARP, A.M.

Instructor in Geology, Columbia University

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY, IN THE FACULTY OF PURE SCIENCE, COLUMBIA UNIVERSITY

HARTFORD

Printed by the State Geological and Natural History Survey

1929

ACKNOWLEDGMENTS

Throughout the preparation of this bulletin the writer has had the benefit of the valued advice and helpful criticism of Professor Douglas W. Johnson of Columbia University to whom he wishes to express his sincere appreciation. In a like manner the other members of the Department of Geology at Columbia University were always ready to lend assistance in the solving of problems appertaining to their special fields. Mainly due to this sympathetic attitude the author has found the writing of this bulletin to be a pleasure rather than a task.

To Dr. W. E. Britton, Superintendent of the Connecticut Geological Survey, are due sincere thanks for the manner in which he made an official relationship so congenial and for the more tangible assistance with which he made the completion of this work a possibility. The author was a trespasser on practically every shorefront property throughout the length of Connecticut, but everywhere he met with the same uniformly courteous treatment, and to the many citizens of Connecticut who forwarded his work in various ways he wishes to express thanks. It is his hope that some of these may gain as recompense some pleasure or information from the reading of this report.

Thanks are due to Miss Bessie Blauvelt for her kindness in typing the original manuscript and to the author's wife, Gertrude S. Sharp, who assisted greatly in the mechanical labor incident to assembling the report.

CONTENTS

	PAGE
Chapter I. Introduction	9
Location	9
Economic Importance of the Shore as a Vacation Resort	10
Value of State Parks at the Shore	12
Growing Interest in Shore Protection	13
Chapter II. Shore Processes	14
The Complexity of Shoreline Problems	15
Waves and Their Work	15
Factors Influencing Wave Work	16
Influence of Waves in Moving Beach Materials	20
Importance of Local Drifting in the Connecticut Area	22
Chapter III. The Character of the Shoreline	24
Summary	33
Chapter IV. The Physiographic History of the Shoreline	34
Pre-Mesozoic	34
Triassic	34
The Fall Zone Cycle	35
The Burial of the Fall Zone Peneplane	35
The New England Upland Cycle	36
The Connecticut Valley Lowland Cycle	38
The Sound Valley Cycle	41
The Regime of the Ice	43
Postglacial Changes of Level	45
Is the Shore Still Sinking?	47
Marine Terraces	50
Summary	50
Chapter V. Postglacial Changes and the Present Shoreline; the Hard Rock Shoreline	51
Comparison of Connecticut and Rhode Island Shores	51
Postglacial Erosion in Hard Rock	52
Slight Erosion at Savin Rock	56
Uneroded Glacial Striae	57
The Influence of Jointing on the Shoreline	58
The Influence of Foliation on the Shoreline	60
Features of the Thimble Island Region	63
Summary	64
Chapter VI. Postglacial Changes and the Present Shoreline; Shoreline Formed of Unconsolidated Deposits	64
District Between the Pawcatuck and Thames Rivers	66
Tombolos of the Groton Long Point Vicinity	66
Clam Point Cuspate Bar	69
Shoreline Between the Thames and Connecticut Rivers	70
Contraposed Shoreline	71
Rock Headlands	72
Goshen Point	73
Shoreline Changes in Old Lyme	73

PAGE

The Griswold Point Compound Spit 76
Small Case of Wave Intercision 77
Shoreline Between Connecticut River and East River, Guilford. 77
Cornfield Point to Lynde Point Light 79
Storm Damage West of Oyster River 81
Menunketesuck Point 82
Storm Damage near Hammock Point 83
Hammonasset Beach 84
The Madison Shoreline 84
The Shoreline Between East River, Guilford and New Haven Harbor 85
Changes in Great and Little Harbors 85
Double Beach Tombolo 86
Wind Action on Beaches 86
Shoreline from New Haven Harbor to the Norwalk River 87
Thickly Populated Shoreline 87
Restoration of Shoreline from New Haven to Bridgeport Harbors 87
Highest Cliffs of Drift 91
Charles Island Tombolo 92
Large Spits 92
Fairfield-Stratford Plain 93
Shoreline from Norwalk River to the New York State Line 94
Norwalk Islands 94
Long Neck and Shippan Points 96
Halloween Park Beach 96
Summary 97

ILLUSTRATIONS

FIGURES

FIGURE

1 Table showing increase in assessed valuation of four Connecticut shore towns since 1900.

2 Wave refraction showing the concentration of wave attack upon headlands.

3 a, the normal shore profile; b, oversteepening of the shore profile by a short storm; c, oversteepening of the shore profile by a long storm.

4 Diagram illustrating the migration of beach drift with wind from the southwest.

5 The wind rose for New Haven and vicinity.

6 Beaches and offshore protection at Rye, N. Y. (modified from Coast Survey Chart No. 222).

7 Outline maps of southern Maine and Connecticut to show comparative irregularity of shorelines.

8 Maps showing fine and coarse textured topography; submergence of the area to the left will yield the most irregular shoreline.

9 Reduced profile showing the slope of the upland and Fall Zone peneplanes.

10 Block diagram showing the relationship of the four peneplanes west of New Haven.

11 Geologic map of Connecticut showing major distribution of rocks at end of the Upland Cycle.

12 North-South cross-section showing Connecticut at the end of the Lowland Cycle.

13 North-South cross-section showing Connecticut and Long Island at the time of formation of the Sound valley.

14 North-South section of southern Connecticut and Long Island during glaciation.

15 Structure section showing present relationship between Long Island and Southern Connecticut.

16 Cliff with talus, and the same cliff with talus removed giving an appearance of wave cutting.

17 Section showing relation between drift and bedrock at Avery Point.

18 Cross-section showing surface and structure of cliff at Savin Rock.

19 Plan of en echelon offset and dovetailing of shoreline in jointed granite gneiss.

20 a, section showing bedrock and soil cover of preglacial hill.
b. same hill during glaciation.
c. submerged to form apparent wave-cut cliff after retreat of glacier.

21 Concentric jointing forming shore at Joshua Cove.

22 Outline map of the shore between the Pawcatuck and Connecticut Rivers.

23 Tombolos of Groton Long Point beach (from Coast urvey Chart No. 358).
24 Diagram of cuspate bar at Clam Point, Mystic Harbor.
25 Restoration of shore plain at Old Lyme.
26 Wave intercision west of Hatchett Point.
27 Outline map of the shoreline between the Connecticut River and New Haven Harbor.
28 Outline map showing restoration of shoreline from New Haven to Bridgeport Harbors.
29 Outline map of the shoreline from Bridgeport Harbor to the New York State Line.

PLATES

I a, View of Forbes Bluffs, cliffs of trap, washed by the waves of New Haven Harbor.
b, Another view of the same Bluffs.
II a, Savin Rock showing nip at high tide level.
b, Phyllite outcrop forming shore at Merwin Point.
III a, Uncliffed headland in an exposed position on Sachem Head (Photograph U. S. G. S.).
b, Joint shoreline at Joshua Cove.
IV a, House at Saybrook Manor beach left on piles on retreat of shoreline.
b, Scene at the head of Joshua Cove (Great Harbor) showing badly eroded peat exposed by the retreat of the sand bar over the marsh (Photograph by Cohen).
V a, Menunketesuck Point, a till island, showing signs of great erosion.
b, Tombolo in Joshua Cove; note slope of the upland.
VI a, Double Beach, a tombolo, in Branford Harbor (Photograph by Gianella).
b, Bar capped by dunes, Morgan Point, East Haven (Photograph by U. S. G. S.).
VII a, Vegetation-covered cliff in till near Pond Point, Milford.
b, Prograded shoreline west of Stratford Point Light.
VIII a, Abandoned seacliff on Welch Point Road, Milford.
b, Charles Island tombolo, Milford, looking North.
(Photograph by A. S. G. S.)

The Physical History of the Connecticut Shoreline*

By Henry S. Sharp, A.M.

CHAPTER I. INTRODUCTION.

Location.

The length of the Connecticut shore to an aviator flying in a straight line along the coast from Rhode Island to New York is 98 miles, but looking downward he sees at a glance all the infinite detail of a ragged shoreline, the rocky islands and wind-swept headlands, the crescent beaches and quiet bays, which make this, the natural southern boundary of Connecticut by far the longest of the State. The wooded hills and green but rocky pastures of the rugged New England Upland lie ever on his right until nearing New Haven he notes a broad lowland dotted with busy villages and farms stretching northward from the Harbor to the horizon. Geologists call this the Central Lowland or Connecticut Valley Lowland, and it naturally divides the State into two upland areas, the Eastern Highland and the Western Highland.[1]

Approaching New Haven the aviator sees the low mass of Long Island 20 miles to the south across the broad and sparkling bosom of the Sound. If he has also flown over the unprotected coasts of Maine and New Jersey, he will quickly realize the importance of the Island as a shelter to the shore beneath him, for even here in the vicinity of New Haven where the Sound is widest, waves sweeping diagonally across it can rarely have an effective fetch of more than 30 or 40 miles. New Haven Harbor where the Lowland passes under the Sound is left behind, and as he points his craft more to the southwest to follow the coast of the Western Highland the airman sees far ahead the shores of the Sound rapidly converging to form at last a narrow strait. The aviator may note all of this, and if it is summer he surely cannot fail to see wings of circling gulls flashing in the sunlight above some rocky islet, the even curve of a wave-fringed beach dotted with the tiny figures of bathers, a protected rockbound bay where white yachts float quietly at rest, and always the wave-decked waters of the Sound sparkling and beckoning in the warm light. Then is he indeed lacking in thought, if he does not wonder at the good chance which placed the varied beauty of all this shore

*Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Faculty of Pure Science, Columbia University.

[1]Rice, W. N., and Gregory, H. E., "Manual of the Geology of Connecticut": Conn. Geol. and Nat. Hist. Survey, Bull. 6, p. 17, 1906.

close to the most densely populated section of the nation where it is easily available to many thousands for their health and happiness.

This bulletin is a study of the origin and evolution of the shoreline pictured above. The entire area here described has been completely mapped by the United States Geological Survey in cooperation with the State of Connecticut on a scale of one mile to the inch. From east to west the topographic sheets covering the shoreline are the Stonington, New London, Saybrook, Guilford, New Haven, Bridgeport, Norwalk, Stamford, and Oyster Bay; these maps are obtainable from the United States Geological Survey, Washington, D. C., at ten cents each. The submarine topography and a narrow strip of the coast are shown on a scale of 1 to 20,000 by the charts of the United States Coast and Geodetic Survey.[1] Coast survey charts on a scale of 1 to 80,000 are also useful in showing larger areas conveniently. A topographic map of Connecticut on a scale of two miles to the inch issued by the United States Geological Survey in 1912 when used in conjunction with a map of Long Island appearing in Professional Paper 82 is most useful in showing the relation of Sound, Island, and mainland.

The entire Connecticut coastal region is traversed by the main line of the New York, New Haven, and Hartford Railroad and is likewise served by numerous trolley lines. For the motorist a rapidly improving system of paved roads provides convenient access to most parts of the shore.

Economic Importance of the Shore as a Vacation Resort.

The shores of a state always have been of great importance in providing a suitable base for the marine industries of fishing and shipping, but only within the last two decades have they become remarkably important as vacation resorts. In New Jersey the value of shore property has increased from about $50,000,000 in 1900 to over $600,000,000 in 1926. Connecticut shore properties show a similar growth and will continue to grow in value for many years as undeveloped parts are occupied. Figure I shows the increase in assessed valuation of four Connecticut summer resort towns since the year 1900. Property owned by non-residents shows the most striking increase in value and is especially significant, since a very large proportion of the non-resident owners are induced to buy their places because of the attraction provided by the waters of the adjacent Sound with its bathing, boat-

[1]Charts on a scale of 1 to 20,000 showing the Connecticut area are: 358 Fishers Island Sound, 359 Thames River-Harbor of New London, 214 Hatchett Point to Goshen Point, 215 Connecticut River entrance, 216 Duck Island to Madison Reef, 217 Guilford Harbor to East Haven River, 218 New Haven Harbor, 219 Milford to Stratford, 220 Stratford to Sherwood Point, 221 Sherwood Point to Stamford Harbor, and 222 Greenwich Point to New Rochelle. These are all obtainable from the United States Coast and Geodetic Survey, Washington, D. C. Prices on application.

Town of	Class of Property	1900	1910	1920	1926
Old Saybrook	Resident	$412,329	$583,084	$838,680	$1,101,645
	Non-resident	$216,864	$378,100	$709,983	$1,668,724
Clinton	Resident	$778,807	$674,894	$1,050,656	$1,515,331
	Non-resident	$157,626	$273,282	$634,026	$1,446,364
Westbrook	Resident	$368,288	$411,784	$597,334	$820,953
	Non-resident	$146,154	$485,500	$877,710	$1,241,953
Milford	Resident	$1,870,155	$5,255,039	$11,386,220	$13,352,347
	Non resident			$7,147,095	$12,277,323

Fig. 1. Table showing increase in assessed valuation of four Connecticut shore towns since 1900.

ing, fishing, and other outdoor activities. Thus this increase in value clearly indicates the growing importance of the shore. A considerable proportion of the property owned by residents is likewise rendered more valuable by the proximity of the Sound, and in Milford, a town showing an assessed valuation of nearly $26,000,000, the Board of Assessors estimates that 60% of the total valuation is due to the attraction of the shore. In the other three towns named the value of property owned by non-residents is 8 or 9 times as large as in 1900, while the property owned by residents has rarely more than doubled in value in the same period of time. In 1926 Milford had 3741 resident and 3639 non-resident tax payers. Since the shore is the principal attraction drawing non-resident owners, these figures give an idea of its importance to the State as a natural resource.

Milford, a town remarkable for its shore development, is an example of the influence of proximity to great centers of population on the occupation of shore property. Situated midway between the large cities of New Haven and Bridgeport, it is also much nearer the metropolitan area of New York City than any other of the three towns mentioned. Almost every available foot of its waterfront is occupied, and it serves as an illustration of the type of development to be expected on the entire Connecticut shore in the not distant future.

The growth of the shore as a vacation resort has followed very closely the increased use of the automobile as a necessity of American life and seems to be dependent upon the convenience of transportation furnished by it. Before the advent of the automobile the impecunious city dweller could spend only an occasional day at a nearby resort. Now he loads the whole family in the old car and drives a couple of hundred miles to spend two weeks at a favorite beach. The comfort and quickness of economic transportation furnished by the automobile is probably the most important single factor contributing to the rapid development of the entire shore of a state such as Connecticut.

Value of State Parks at the Shore.

In some states the shore has been taken up so completely that it may be difficult for a person not owning waterfront property to gain access to the beaches. In many parts of Connecticut this is true, but fortunately it can never be entirely true, for with admirable foresight the State is purchasing for public park use properties having desirable frontages upon the Sound. Hammonasset Beach in the town of Madison is such a State Park; It now consists of over 900 acres of land having a Sound frontage of nearly two miles of beautiful sand beach. It is equipped with a comfortable and adequate bathing pavilion, with free parking space

for several thousand motor cars, and with a large number of sanitary camp sites. This Park is maintained for the use of the public by the State Park and Forest Commission and should be a matter of pride to every citizen of Connecticut. The purchase of several more such parks is contemplated and should be pushed to completion in the near future, for shore property continues to rise in value, and delay can mean only an increase in purchasing price. Financially these parks are good investments, for they will continue to rise in value with the increase in value of surrounding property; as an investment in health and happiness for a large number of citizens of the State their value cannot be overestimated. The beautiful shoreline on the Sound is surely as important a natural resource of Connecticut as is its water power, and at least portions of it should be acquired by the State for the use of all its citizens.

Growing Interest in Shore Protection.

The increasing use and value of acreage on the shore naturally resulted in many complications and difficulties. When the sea washed away a beach occupied by nothing but poison ivy no one noticed the change, but when a beach covered by a row of cottages is partly destroyed there are many to object and to fight the forces of destruction. When a strip of pastureland a few feet wide was carried away, it caused little financial loss; now, when such strips are no longer pastureland, but form resort properties valued at thousands of dollars per acre, the owners are willing to spend large sums in strenuous resistance to the onslaughts of the waves. In some regions this erosion may mean an almost hopeless struggle for waterfront municipalities and private owners. In Connecticut, thanks to the rockiness of much of the coast and the protection afforded by Long Island, the problem of wholesale erosion is seldom involved, but even here mile after mile of shorefront can be seen protected by heavy and expensive structures which are themselves often partially destroyed. Mile after mile of low, barren cliffs eroded in unconsolidated materials show by the overhanging and fallen turf that someone is being robbed by the sea. Here an interrupted road, there a house crazily tilted, show how recent and relentless the attack has been. The sea is no respector of persons. On the Connecticut coast single property owners can be found who have spent over $10,000 in protecting a very short waterfront, but on the Long Island and New Jersey coasts and in the southern states the sea often has levied a much heavier tax upon property owners Municipalities are also spending large sums; Wrightville, a summer resort town in North Carolina, having a winter population of but 22 persons has

spent $60,000 in protecting its beaches; Long Beach, New York, has spent over a half million dollars in protection but continues to suffer at every heavy storm. The State of New Jersey has spent millions of dollars in protection and continues to suffer great damage every winter, but at the present time is fully alive to the tremendous value of her beaches and is organizing to protect them more effectively.

In the vicinity of large cities the demand for greater bathing facilities has resulted in the construction of artificial beaches; these may be built in favorable locations, where natural beaches are inadequate, by dumping sand along the shore and by means of groins preventing its rapid removal. In some places these beaches have cost immense sums; New York City has spent over $2,000,000 in the improvement of its Coney Island Municipal Beach; on the Sound such beaches have cost Stamford, Westchester County, and other public bodies many thousands of dollars.

The public, recently awakened to the value of its beaches, has formed the first organization in this country devoted solely to the proper protection and utilization of our shores. In 1926 the National Research Council through its Committee on Shoreline Investigation succeeded in arousing enough interest among the authorities of the various states on the Atlantic and Gulf seaboard to justify the Governor of New Jersey in calling a conference on coast protection at Asbury Park. The meeting was attended by delegates from 16 states and resulted in the formation of the American Shore and Beach Preservation Association, which in its short life has done much to attract attention to the problems of shore protection and to aid in solving them. Its most important function is to provide a rallying ground for all those interested in the fight against the relentless waves and in preserving our beaches as heritage for future generations. Its steady growth is an encouraging evidence of the awakening of public interest in beach protection.

CHAPTER II. SHORE PROCESSES.

A discussion of the underlying principles of coastal erosion cannot be limited by the narrow boundaries of a political division such as a state, and much that follows is necessarily taken from sources beyond the borders of Connecticut. At the same time no extended treatment of the subject is attempted here, and the reader who wishes to go more fully into details is referred to the authoritative work of Johnson[1] from which much that appears in this chapter has been derived.

[1]Johnson, D. W., "Shore Processes and Shoreline Development," 584 pp., John Wiley and Sons, New York, 1918. This book contains an extensive bibliography.

The Complexity of Shoreline Problems.

At the shore the geologist studying the surface features of the earth meets some of his most complicated problems. There the landforms carved to various stages of completion by running water, wind, or ice are modified or entirely destroyed by the ceaseless movement of the ocean. The problems become even more difficult, if several of these agents succeed each other in carving the forms presented to our view. This complexity is well illustrated by the still debated question of the origin of fiords, where the generally accepted explanation assumes at the beginning valleys cut by stream erosion perhaps along lines of structural weakness. Later glaciers push down these valleys and, finally melting, leave facetted spurs and oversteepened walls as evidence of their erosive ability. At the disappearance of the glaciers, either because the ice has eroded the valley bottoms below sealevel, or because the sea has risen in relation to the land, the ocean waters enter the valleys forming fiords, the most characteristic features of many glaciated coasts. Not only does such a complicated history as that just given demand the attention of the geologist, but his difficulties are increased by lack of knowledge concerning the precise manner in which the ocean does it work.

A careful analysis of the erosion and transportation occurring along our shores seems to show that waves and tides must be the principal agents involved. Although the results accomplished are usually due chiefly to a single one of these agents acting alone, they may often work together to such a degree that it is difficult to arrive at a correct estimate of their relative importance. For this reason it is desirable to discuss each agent separately before attempting the more difficult task of evaluating the relative importance of several complicated interacting forces at the actual shore.

Waves and Their Work.

Waves, usually the more important of the agents producing changes in the shoreline, are of two types: waves of oscillation and waves of translation[1]. The wave of oscillation is the ordinary wind wave or swell of the open ocean characterized by a succession of crests and troughs. Water particles in this type oscillate through a circular or elliptical orbit moving forward in the crest and backward in the trough of the wave. One oscillation is made each time the wave passes through the distance between two adjoining crests or one wave length. In deep water the orbit is circular; with increase of depth beneath the surface the size of the orbit rapidly decreases, and as the influence of the bottom is felt the circle becomes an ellipse with its major axis parallel to

[1]Johnson, D. W., idem, pp. 7-38.

the bottom. At the bottom the movement is a simple to and fro oscillation with the forward movement practically compensated by the backward.

The wave of translation is most commonly seen where shoaling causes oscillatory waves to break and hurl their waters forward in a body. They are also formed by the forcing of some object into the water or by the passage of a boat. In these waves the particles of water are bodily shoved ahead; moreover there is no compensating backward movement, so that debris may be carried forward by a series of leaps comparable to the transportation of material along stream bottoms.

As agents of destruction, waves exert tremendous force, and many authors have listed evidences of their giant power. Matthews[1] tells of two concrete blocks weighing 1,350 and 2,500 tons which were displaced by the waves during severe storms at Wick, Scotland; at Bilboa, Spain, a mass weighing 1,700 tons was carried 105 feet. The same author says that the force of impact is often 3 tons per square foot, and that such waves striking seawalls may throw water over 100 feet in the air whence it falls upon the wall or behind it with terrific force. He advises that no obstruction be placed seaward of a coast defense, less the comparatively harmless waves of oscillation be changed to dangerous waves of translation. Wheeler[2] cites a single storm at Cherbourg, France, where 12 ton blocks were overturned, while more than 200 blocks weighing 4 tons or more each were carried over a 20 foot embankment. Johnson[3] has listed a large number of such examples of the power of waves of translation, but those given above will suffice to furnish an idea of the size of the forces involved. Such exceptional occurrences are not expectable in Connecticut, but at every storm the coast of this State is vigorously attacked by similar waves.

Factors Influencing Wave Work.

The work accomplished by waves is dependent upon their size and character, the direction of their approach, and the steepness of the beach profile. Waves approaching the shore on a calm day will usually be of moderate size, and when the underwater profile is gentle and adjusted to the wave size, the net result will usually be accretion. If the underwater slope is steep, waves of similar size may cause erosion. This difference in action is due to gravity. On a shore of gentle slope the slightly greater forward movement of particles in the wave of oscillation results

[1]Matthews, E. R., "Coast Erosion and Protection," pp. 1-195, London, 1918. See p. 3, 4, 78.
[2]Wheeler, W. H., "The Sea Coast," 361 pp., London, 1902, p. 18.
[3]Johnson, D. W., "Shore Processes and Shoreline Development," pp. 63-71, New York, 1918.

in a slow landward advance of material. Where the profile is steep, the backward oscillatory movement plus the pull of gravity may overcome the forward oscillatory motion and cause a slow seaward migration of material.

When wind and waves are both driving directly toward the land, the sealevel on such a lee shore may be raised several feet above normal. Under such conditions a hydraulic current running seaward along the bottom may be formed with marked erosion of the shore. Escher[1] in his studies on the Netherlands coast finds that when onshore storms have raised the waterlevel to the edge of the permanent dune belt, such a seaward undertow ensues causing extraordinary dangerous erosion of the dunes, which are the most dependable coast defenses of the Dutch. Such currents may make bathing very perilous, and the same author says that they annually cause many drownings along the Dutch coasts. When combined with extraordinarily high tides onshore storms are likely to be unusually destructive, since the waves are able to attack places ordinarily beyond their reach.

On the other hand, when the wind is from the shore, and the seas fairly calm, conditions are best for accretion to the land. The wind blowing off shore lowers the level of water at the beach in relation to that further out, and a landward hydraulic current comes in along the bottom carrying material with it. In New Jersey this action is so well exemplified that it has become an axiom of the fishermen that a west wind "builds up the beach."[2]

Waves approaching the shore at a marked angle are usually rare due to wave refraction, a process somewhat analogous to the refraction of light, and caused by the difference in rapidity of wave advance in different depths of water. The water is ordinarily deeper opposite bays than headlands, and for that reason an irregular coast is likely to show wave refraction most advantageously. A straight wave (ad, Fig. 2) advancing normal to the general trend of such a coast at an even rate of speed will first feel the effects of bottom retardation opposite the headlands, while its advance will be relatively unimpeded opposite the bays. Due to the difference in speed the faster moving portions of the wave rush ahead of the slower, and the wave front gradually takes the position mn. This progressive but unequal retardation of speed continues until finally all parts of the wave are moving through water at uniform depth, when the velocity of advance becomes uniform, and the wave front takes the position xy more or less parallel to the major irregularities of the shoreline. As shown by the dotted lines in Fig. 2, refraction will cause a concentration of wave energy from b to c upon a narrow stretch of

[1]Escher, B. G., "Invloed van stormen op de Kustvormig," in "Ons Eigen Tijschrift," Vol. IV, pp. 65-69, 1926.

[2]Patton, R. S., "Problems Involved in Coast Erosion," Military Engineer, Vol. XVI, p. 459, 1924.

headland shore, while an equal amount of energy from c to e will be dissipated over a much greater bay shoreline. Such a distribution of energy means that the headlands will be worn back more rapidly than the bays, and the shoreline gradually straightened. At the best, wave refraction is never ideally developed; if deep water is immediately offshore the braking effort of the bottom is less important, and waves may approach the shore at considerable angles. Storm gales may also drive them onshore at marked angles, when erosion is apt to be very rapid.

Another factor of great importance in determining the force with which waves attack the shore is the steepness of the underwater profile. Fig. 3, a, shows a shore profile with a gentle under-

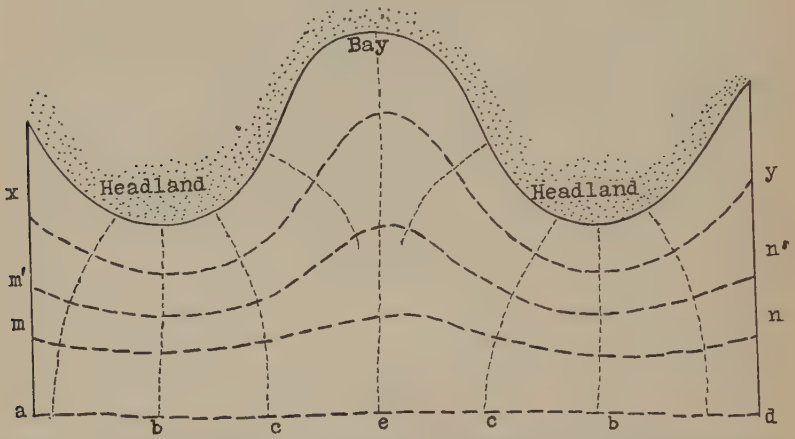


Fig. 2. Wave refraction showing the concentration of wave attack upon headlands.

water slope in the direction from which wave attack must come. With such a profile only after a prolonged storm can the shore itself be eroded, because the shallow water will cause the heavy waves to break far out where they can do little harm. In addition the waves will be occupied for a long time in steepening the profile far from shore, and until they have carried away enough material to allow large waves to approach nearer, cannot attack the shore vigorously. Short storms will be over before this can happen and may leave the profile shown in Fig. 3, b, which the process of deposition in calm weather may quickly restore to normal. Thus the underwater erosion caused by a succession of short storms may not be cumulative, whereas one long storm may steepen the profile (Fig. 3, c) sufficiently for large waves to reach the shore and cause grave destruction of property. Shores having steep underwater profiles are therefore much more subject to

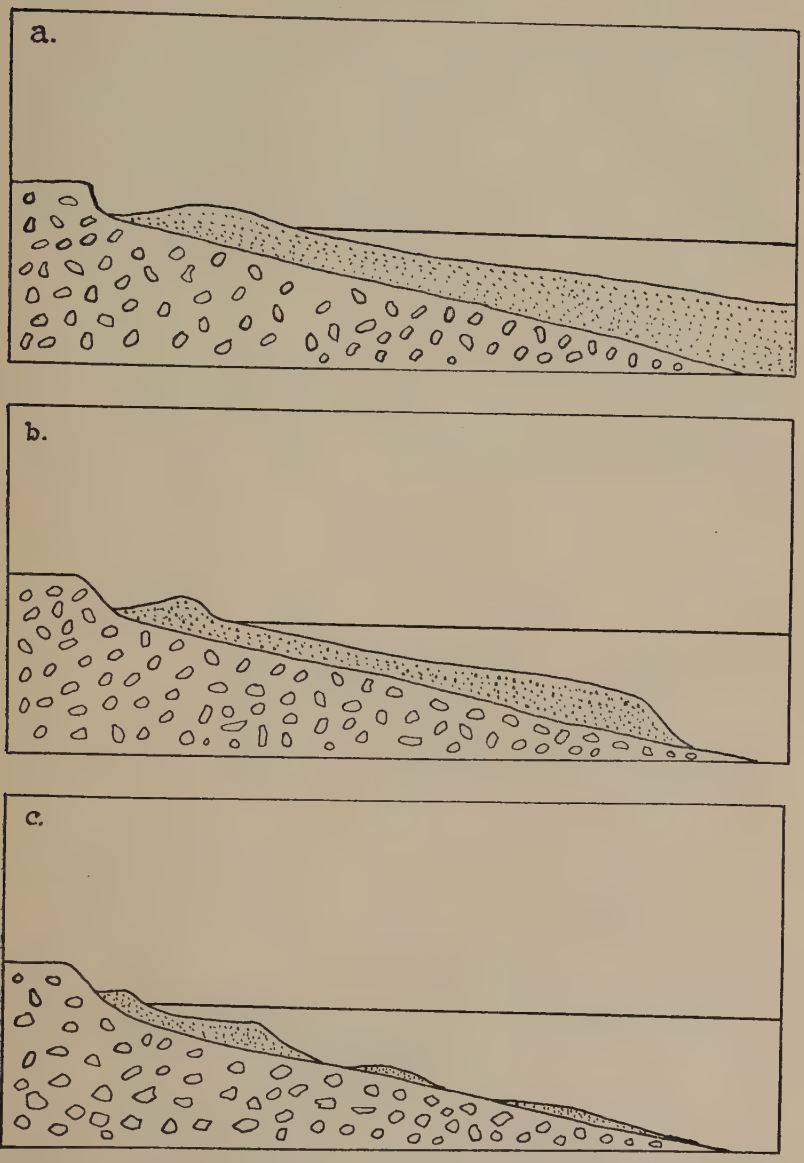


Fig. 3. a, The normal shore profile; b, oversteepening of the shore profile by a short storm; c, oversteepening of the shore profile by a long storm.

damage than those whose gentle underwater slopes act as a natural protection.

In the past authorities have differed greatly concerning the relative importance of tidal and wave currents in the transportation of shore debris, and, if anything, tidal currents were believed to be the more important agents forming the depositional features of the shoreline. Now, however, the concensus of authoritative opinion seems rightly to point to wave-induced currents as the principal carriers of shore material.

Influence of Waves in Moving Beach Materials.

Wave currents are the producers of beach drifting and longshore drifting, probably the most important means by which littoral debris is transported. The origin of beach drifting[1] is so well understood that it will only be necessary to say that it is caused by waves coming obliquely onshore and forming a swash which carries the debris in the direction of wave movement up the

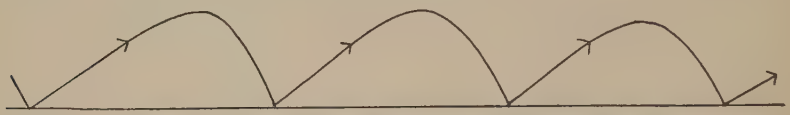


Fig. 4. Diagram illustrating the migration of beach drift with wind from the southwest.

beach, whence the force of gravity causes it to return almost directly down the slope. As shown in Figure 4, wave following wave thus produces a net progession of material to leeward by a series of parabolic leaps. In addition to the above movement the thin sheet of debris-laden swash may be blown appreciably to leeward by the brisk winds commonly associated with oblique onshore waves. The importance of beach drifting is demonstrated by the accumulation of sand on the windward side of any obstruction hindering the movement along the shore. Material is transported by this process along the whole gentle and shallow underwater slope exposed to wave attack, and, as opposed to drifting at the immediate shore, may be called longshore drifting[2]. Along the New Jersey coast longshore currents caused by waves driving obliquely onshore may have a velocity of 7 miles per hour, and on such a straight shoreline can carry material for long distance in one direction. Longshore and beach drifting may be conveniently designated under the one term, shore drifting. Such prominent features of the seacoast as Sandy Hook and Rockaway

[1]Johnson, D. W., "Shore Processes and Shoreline Developments," pp. 94-103.
[2]Report by Board of Commerce and Navigation, New Jersey, on the Erosion and Protection of the New Jersey Beaches, pp. 39-40, 1922.

Point in the Lower Bay of New York have been built by shore drifting. Their size and rapid growth testify to the strength and importance of the process.

In the past all great depositional forms, such as those just mentioned, were thought to have been caused by tidal currents in the belief that shore drifting could build nothing but the most insignificant features. But it is only necessary to point to Presque Isle on Lake Erie, the bayhead bar forming Duluth Harbor on Lake Superior, or the great spit forming Toronto Harbor on Lake Ontario to show that large depositional features can be

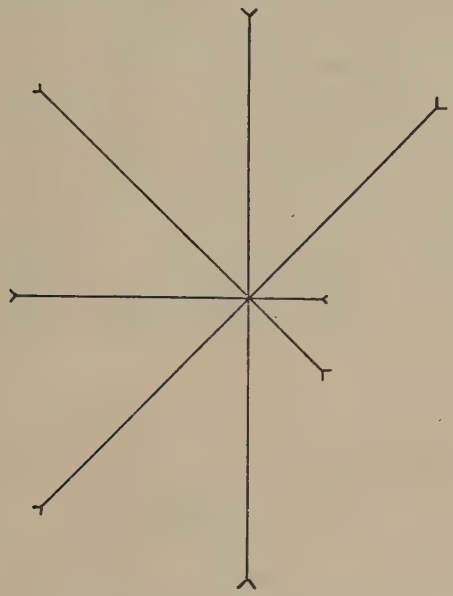


Fig. 5. The wind rose for New Haven and vicinity.

built by smaller waves than those of the ocean in bodies of water where the tidal currents must be practically non-existent.

The direction of drift movement may be to a considerable extent predictable. It will usually be in the direction of the prevailing wind, but a single great gale may form waves transporting more material a greater distance than waves caused by the prevailing wind have been able to do in months of slow but steady work. If other conditions are similar, the wind coming over the greater fetch of open water will form waves dominant in directing the movement of drift. The length of fetch is so important that waves generated by a weak wind (blowing across a broad expanse of sea) may be dominant over those caused by a much

stronger wind blowing over a smaller fetch of open water. Where these conditions occur, examination will show a seemingly anomalous movement of material against the stronger wind. The transportation of debris on such a beach has often been erroneously ascribed to tidal currents, since without due consideration of the influence of length of fetch the direction seemed absolutely inconsistent with the usual explanation of beach drifting, which demanded that movement be with the prevailing or stronger wind. The direction of beach drifting may vary from day to day according to the wind, but for a given stretch of coast observations over a period of years will usually show that the transportation of material has been preponderantly in one direction under the influence of some of the factors mentioned.

The relative importance of the wind from each quarter may be graphically shown by "wind roses". These are made by multiplying the number of hours of duration of wind from each quarter by the average hourly velocity; the results are then plotted in lines extending from a common center toward the direction from which the given wind blows and prolonged a distance proportionate to the strength of that wind. The wind rose for New Haven (Fig. 5) covering a period of 24 years is compiled from annual roses furnished by the New Haven Weather Bureau and is believed to give a fair representation of the relative wind strengths on the Connecticut coast.

Importance of Local Drifting in the Connecticut Area.

Straight coasts such as those of New Jersey and southern Long Island are ideal for the development of longshore currents setting in the same direction for great distances. Conditions are there quite uniform, and the movement of drift easily explained. Both theory and observation lead to the belief that the drifting of material on the irregular Connecticut coast must be controlled by the local configuration of the shore in relation to the onshore winds. Important longshore currents are not to be expected. The application of the wind rose will be a purely local problem, and due to differences of exposure to the waves the direction of beach drifting may change greatly within short distances.

An enlightening example of the influence of length of fetch and strength of wind in determining the movement of beach material can be cited from Rye, New York, on the north shore of Long Island Sound. The shoreline here is in every detail comparable with that of Connecticut, and the movement of debris can be taken as typical of the beach drifting to be found on the Connecticut or any other coast of similar irregularity. Three beaches, Meadow, Rye, and Oakland, all near the town of Rye, show a distribution of sand pointing to their origin by beach drifting. These are

immediately adjacent to each other and are of the pocket beach type, although none is situated in such a deep indentation of the coast as to be entirely protected from oblique onshore waves. The area is shown on Coast Survey Chart 222.

Meadow Beach lying furthest to the northeast is situated in a little bay formed by two southeastward projecting promontories. Along the rear of the beach is a stone wall. The northeastern end of this beach has a broad strip of sand which narrows rapidly toward the southwest until only a few feet of sand remain before the seawall. The cause of this uneven distribution is not far to seek. A short distance offshore are the Transport Rocks (Fig.

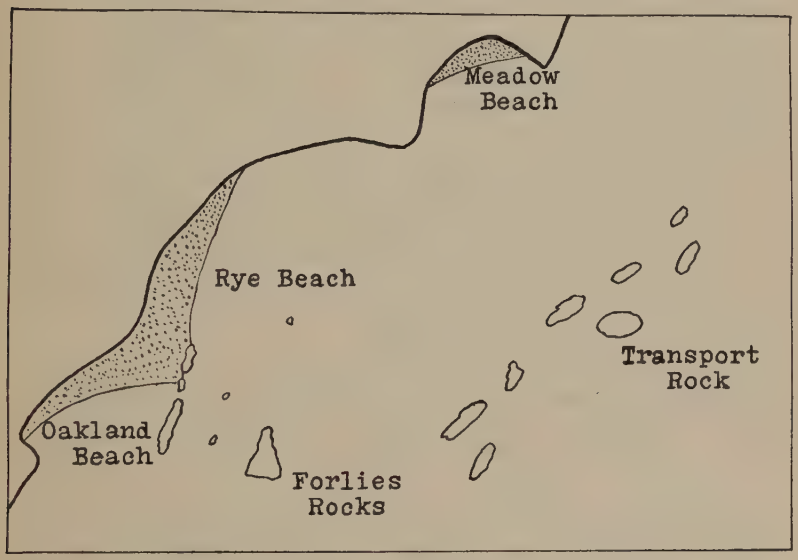


Fig. 6. Beaches and offshore protection at Rye, N. Y. (Modified from Coast Survey Chart, No. 222).

6) largely protecting the beach from the onslaught of southeast winds. To the east the waves can wash in between the Transport Rocks and Manursing Island unhindered, while to the south the beach is also exposed. The wind rose for this area (Fig. 5) shows that the east winds are less important than the southerlies, so that here the dominant waves breaking upon the beach are from the south. Meeting the northeastward extending shore obliquely they cause drifting toward the northeast until the northern point of rocks breaks up the movement, and the sand is deposited to form the wide strip of beach.

A short distance southwest of Meadow Beach lies Rye Beach. Several times larger than the former, it too is situated before a

seawall between two short rocky projections of the coast, one of which is the southern point of Meadow Beach. Again the distribution of sand is uneven; this time the southwestern end of the seawall is faced by a broad, beautifully even sand beach, whereas toward the northeast there is no sand at all, and the seawall stands in several feet of water. This is exactly the opposite of conditions at Meadow Beach, and again the presence of offshore rocks explains the seemingly anomaly. To the south and southeast stand the Forlies Rocks protecting the southwestern portion of the beach from waves generated by the important south and southeasterly winds. To the east the beach is protected by the Transport Rocks, but to the north of these the strong northeasterly winds can bring waves upon Rye Beach from a long reach of open water. Southeasterly beach drifting is hence set up, and the interference of the southern rock point causes deposition on that portion of the beach.

A short distance further south is Oakland Beach, which is north instead of south of the road shown on the chart. Here again the position of rocks offshore should be noted. From north through east the beach is well protected by the encircling Forlies Rocks, but toward the southeast the beach is more exposed. According to our theory, southeast waves should here cause drifting in a northerly direction, and the beach should be wide at the northern end. In the field one glance is sufficient to show that the facts conform to our expectations.

A review of the conditions described above shows that two of the beaches examined had a greater accumulation of sand at their northern ends, while the third, lying between the two, was much broader at the southern end. This irregular distribution of sand is a strong argument against the presence of extended longshore drifting in this locality, as well as along the entire northern shore of Long Island Sound where shoreline conditions are much the same. Beach drifting under control of the immediate local conditions is seen to offer a satisfactory explanation of the unusual distribution of debris and is believed to be the principal process of transportation on the entire Connecticut coast. Thus, waves, which are the most important agents of erosion, prove also to control the transport of shore materials.

CHAPTER III.

The Character of the Shoreline.

The sequence of events leading to the formation of the present shoreline of Connecticut was not simple. Long before the coming of the glaciers the area which was to make the Connecticut coast had undergone a series of geologic changes which were to give it the most interesting history of any portion of the coast of

the eastern United States. Postglacial erosional and depositional changes were to transform it in minor detail, but its major outline was determined by events of an earlier time. The recent history of erosion and deposition is of small import, when compared with that great series of events which ended when the sea finally assumed its present level in respect to the land. In Chapter IV the history will be treated in detail, while the present chapter will be restricted to a consideration of the place of the Connecticut shore in a genetic classification of shorelines. In addition the causes for the remarkable difference in irregularity between the shorelines of Maine and Connecticut, both having very similar histories will be discussed as fully as is appropriate in this bulletin.

In the past shore lines have been described both empirically and genetically, but due to the influence of American writers on geomorphology the genetic type of description is now very much in the ascendency. German writers have commonly used the empiric method, and the Connecticut coast has been briefly treated in such manner by Meinhold.[1] Under the influence of W. M. Davis geomorphologists in this country have quite generally adopted the genetic form of description for all landforms. Nowhere is this better illustrated than in Johnson's[2] monograph on the New England-Acadian shoreline, in which some points on the Connecticut coast are figured and briefly discussed. Reference to the two books just mentioned will afford an excellent comparison of the empiric and genetic type of landform description.

Shorelines have been divided by Johnson[3] into four major classes according to their origin: "I. Shorelines of Submergence, or those produced when the water surface comes to rest against a partially submerged land area; II. Shorelines of Emergence, or those resulting when the water surface comes to rest against a partially emerged sea or lake floor; III. Neutral Shorelines, or those having essential features which do not depend on either the submergence of a former land surface or the emergence of a former subaqueous surface; IV. Compound Shorelines, or those where the essential features combine elements of at least two of the preceding classes."

When a region has been subject to stream erosion for a long period of time, and is then partially submerged by a rise of the water level in relation to the land, the water enters the former stream valleys and following the contours of the surface may make a shoreline whose irregularity is very great. River valleys, which have been flooded in this manner by the sea, are known as

[1]Meinhold, Felix, "Die Kuste der mittleren atlantischen Staaten Nordamerikas," 89 pp. Crimmitschau, p. 44, 1904.
[2]Johnson, D. W., "The New England-Acadian Shoreline," 608 pp., John Wiley, New York, 1925.
[3]Johnson, D. W., "Shore Processes and Shoreline Development," p. 172.

drowned valleys or estuaries. The Thames, the Housatonic, and the Connecticut Rivers in this state are good examples of estuaries, and in each case the tides are felt far above the river mouth. Shorelines which are thus determined by the partial submergence of a former land surface as stated above are called shorelines of submergence. The entire Connecticut shore in common with the whole stretch of coast from New York to New Brunswick has long been recognized by geologists as a good

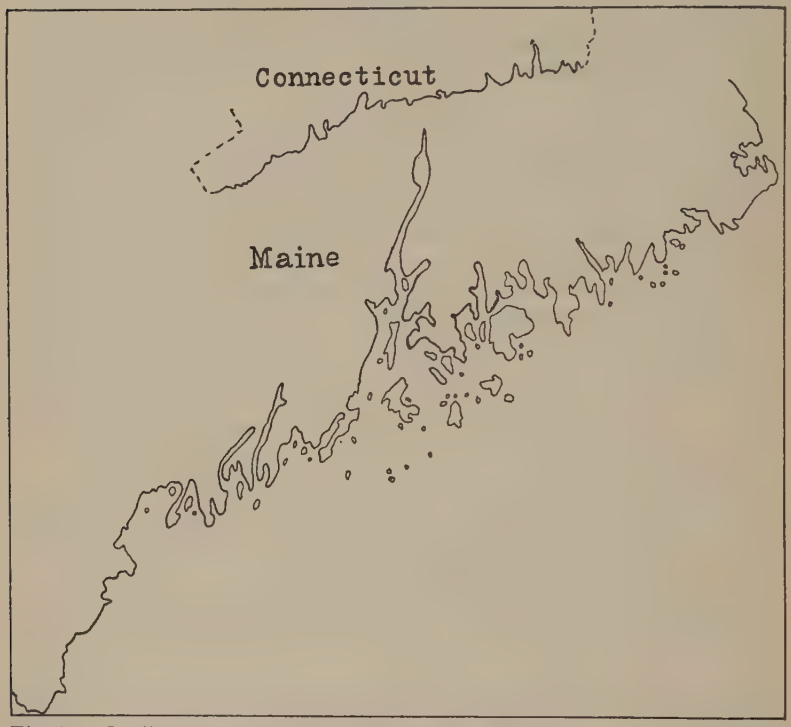


Fig. 7. Outline maps of southern Maine and Connecticut to show comparative irregularity of shorelines.

example of a shoreline of submergence. With this in mind the three other types of shoreline may be disregarded, and the origin of the Connecticut shore discussed in detail.

Although both are recognized as shorelines of submergence, the Connecticut shore is very much more regular in outline than that of Maine. True, the Connecticut shore is irregular in detail, but when compared with the Maine shoreline, which is irregular both in detail and major outline, it seems almost proper to call it a rectilinear coast The topographic maps of the United States

Geological Survey bring out the truly striking difference in regularity of the two shorelines to best advantage, but even small scale outline maps such as Fig. 7 show the much greater regularity of the Connecticut shore. Figures supplied by the United States Coast and Geodetic Survey[1] giving the tidal shoreline, unit measure 1 statute mile, of the two states prove that the difference in outline is as large or larger than it appears on the map. With this unit measure Connecticut has 126 miles of mainland shoreline, Maine over 4 times as much, or 558 miles; Connecticut has 18 miles of island shoreline, Maine over 40 times as much, or 761 miles. The total length of the Connecticut shoreline by this measure being 144 miles, while Maine's shore is over 9 times as long, or 1,319 miles in length. If the shorelines of both states were exactly straight, Maine's would be only a little more than twice as long as Connecticut's. These measurements prove conclusively that the shoreline of Connecticut is relatively much more regular than that of Maine. The difference in regularity between the two shorelines is further brought out by the islands; Connecticut has one island of bedrock measuring over a mile in length, while Maine has over 100 with the largest, Mt. Desert Island, about 15 miles in diameter. In Maine the distance from Lubec to Eastport as the crow flies is 3 miles, but it is 100 miles[2] along the shore. In Connecticut one often finds himself "so near, but yet so far" from the opposite shore of an inlet, but the proportion in miles never approaches 33 to 1. That Connecticut's shore is more regular than Maine's is further demonstrated for each state by comparing the width of a belt bounded on the north by a tangent passing through all the bayheads and on the south by a similar tangent drawn through the headlands and the seaward ends of islands. In Connecticut such a belt rarely exceeds a width of 1 or 2 miles, whereas in Maine the belt may attain a width of over 40 miles and probably averages over 10 miles for all the coast east of Portland.

The Maine shoreline is then much more irregular than the Connecticut. Once having accepted this fact it becomes necessary to search for a difference or differences in physical history which may account for the greater regularity of the Connecticut shore. The following hypotheses are discussed as possible causes of the difference in outline between the two coasts:

1. There may be a difference in the stage of development of the two shorelines. If one were formed of non-resistant and the other of resistant rock, and both had been exposed to erosion an equal length of time, the former would be more mature and hence

[1] "Lengths in Statute Miles of the General Coast Line and Tidal Shore Line of the United States and Outlying Territories," U. S. Coast and Geodetic Survey, Serial No. 22, p. 2, 1915.

[2] Bastin, E. S. and Williams, H. S., "Eastport Folio," U. S. G. S. Folio No. 192, p. 1. 1914.

straighter. If two shores, formed of equally resistant material, were submerged at different times, the earlier submerged would have suffered more erosion and hence be more mature and straighter. In the case under discussion it is apparently unnecessary to consider at length any such possibilities as the above, since it is generally recognized that both states have youthful shorelines with no appreciable difference in stage of development.

2. There may have been a difference in the texture of drainage of the two areas before submergence. (Fig. 8) Obviously, if the area in Maine, which was to be submerged, had many more streams than the Connecticut area, submergence of the former would cause the water surface to intersect more valleys thus forming a more irregular shoreline. Examination of

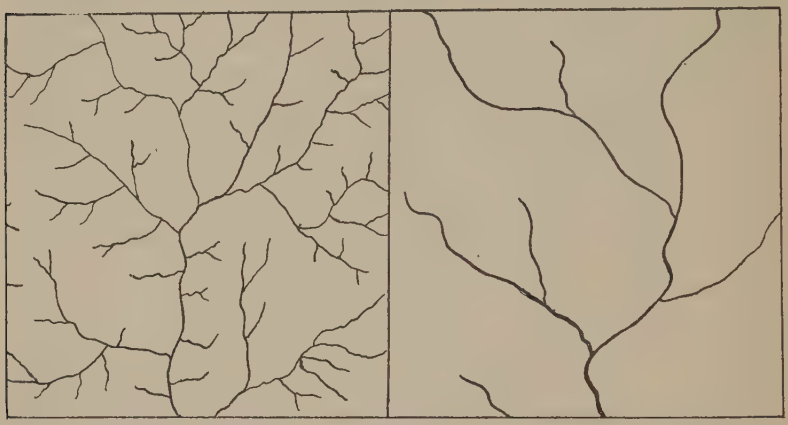


Fig. 8. Maps showing fine and coarse textured topography; submergence of the area to the left will yield the most irregular shoreline.

the topographic maps covering the two areas seems to show no such difference in texture. Apparently the more regular shoreline of Connecticut cannot be due to a coarser textured topography before submergence.

3. It may be due to a difference in the trend of the geological structure of the two coasts. Maine and Connecticut are included within the New England Upland physiographic province, characterized by complexly faulted and folded metamorphic rocks into which have been intruded igneous masses of various shapes and sizes. Both regions have the structure of complex mountains, and available geologic maps show the shores to be composed chiefly of an alternation of granitic and other igneous bodies with highly metamorphosed crystalline schists and gneisses. The structure is very similar on both coasts and cannot be invoked to explain the difference in regularity.

If, however, of two shorelines, one cuts across the structure at a marked angle, and the other parallels the structural trend quite closely, a great difference in the regularity of outline of the two shores is assured. This influence of the "grain of the country" is well shown in Maine, where Johnson[1] has drawn attention to its influence on coastal outline. There, as is usually true elsewhere, the shoreline is most uneven when its general direction truncates the strike of the folds. This is caused by the development of long subsequent valleys parallel to the structure before submergence; when drowning occurred the sea flooded them for long distances inland forming a multitude of long peninsulas and islands. The United States Geological Survey Folios[2] of the Maine coast show that from New Brunswick to Portland the shore truncates the structure at a large angle, and this coincides exactly with the extent of the most irregular shoreline. Southwest of Portland both the shore and the structure[3] trend northeast and are practically parallel. Here the regularity of the shoreline is comparable to that of Connecticut.

What is the relation of the structural trend and shoreline direction in Connecticut? If they are parallel as in southwestern Maine, the cause of the comparatively more regular Connecticut shore may lie here. Although structural trends in Connecticut are by no means so marked as in many parts of the Appalachians, a brief examination of the topographic maps of the State will convince anyone that there is a very strong general tendency for the minor streams to follow a nearly north-south direction. Geologists familiar with the influence of structure on topography would immediately interpret this as indicating the probable existence of alternating resistant and less resistant rock layers striking approximately north. Field studies by many geologists abundantly corroborate this conclusion. Barrell[4] states that the structure strikes toward the sea instead of parallel with it, and that the shoreline of southern New England cuts across the geologic formations at a marked angle. He further notes that the secondary drainage takes advantage of the foliation and extends north-south.[5] Attention is drawn to the elongated hills extending in the same direction by Rice and Gregory,[6] who state that this is the general direction of the foliation of all southern New England, and that this structure has been the controlling factor in producing the form and direction of the hills, although major faults

[1]Johnson, D. W., "The New England-Acadian Shoreline," pp. 8-16.
[2]U. S. G. S. Folios No. 192, Eastport, Me.; No. 149, Penobscot Bay, Me.; No. 158, Rockland, Me.
[3]Katz, F. J., "Preliminary Report on the Geology of the Portland and Casco Bay Quadrangles," Maine St. Water Storage Comm. Annual Report., 3, pp. 171 and 177, 1913.
[4]Barrell, Joseph, "The Piedmont Terraces of the Northern Appalachians", Am. Jour. Sci. 4th Ser., Vol. XLIX, p. 249 and 409, 1920.
[5]Ibid. p. 248.
[6]Rice, W. N., and Gregory, H. E., "The Geology of Connecticut", Conn. Geol. and Nat. Hist. Surv. Bull. 6, p. 75 and 76, 1906. This bulletin contains a geologic map of the entire state.

extending in the same direction may have had some influence. They call the general surface form of Connecticut a "series of north-south ridges".

Even in regions underlain by such fairly massive rocks as the Stony Creek granite gneiss, the foliation has exerted enough influence on the topography to cause the shores of coves extending for considerable distances into the land to coincide very closely to its trend. Sometimes the shore will be seen to follow a single plane of foliation for several hundred feet before it is interrupted by a joint and moves over to follow another parallel plane. In the Stony Creek region the Thimble Islands extend into the sea with the trend of the foliation for a long distance indicating that the courses of streams now drowned were governed by the trend of structure even in granite gneiss areas.

Apparently from the evidence put forth above it can safely be stated that the structural trend in Connecticut forms as marked an angle with the coast as it does in Maine. Furthermore it has had as great an influence on the topography, so that the great difference in the regularity of the shorelines of the two states cannot be due to a difference in the orientation of rock structures with reference to the sea.

4. The difference in regularity of the two coasts may be due to a difference in the amount of submergence. If the irregularity of shorelines varies directly as the amount of submergence, and Maine has been more deeply submerged than Connecticut, the geater irregularity of the shore of the former state may be wholly or partially explained. The deeper submergence of the Maine area is generally admitted, and Johnson[1] has estimated the total drowning as more than 1200 feet on the basis of the depth below sealevel of the drowned inner lowland forming the Gulf of Maine. Long Island Sound likewise occupies a drowned inner lowland the depth of which reaches aproximately 300 feet below sealevel, although some of this may be due to tidal scour. The submergence in Maine has thus been apparently much greater than that in Connecticut.

Greater submergence, however, cannot be accepted as a cause of greater irregularity. The writer has carefully analyzed the various factors, which might influence the comparative irregularity of two coasts submerged to different depths, and has come to the conclusion that any difference in irregularity due to difference in submergence would tend to make the less deeply submerged coast the more irregular. The steps involved in this analysis are of a highly technical nature, and for that reason are omitted from this bulletin, which is intended for the use of the layman in geology. In the case here under consideration it may be concluded that differences in the amount of submergence have little effect

[1]Johnson, D. W., "The New England-Acadian Shoreline", p. 401.

in making the Connecticut shoreline more regular than that of Maine.

5. The difference in irregularity may be due to the submergence of two entirely distinct peneplanes[1] sloping underneath the sea at different angles. It is now recognized that, as shown in Figure 9, at least two important erosional surfaces bevel the crystalline rocks of Connecticut. Of these the New England Upland peneplane slopes southward about 15 feet per mile, while the older surface for which the author has, for reasons given in detail elsewhere[2] proposed the name "Fall Zone peneplane" slopes southward approximately 50 feet per mile. The place of the Fall Zone and Upland peneplanes in the physiographic history of the area is discussed in Chapter IV.

The Fall Zone peneplane becomes entirely submerged somewhere south of Maine, and in that state the more gently sloping New England Upland peneplane forms the submerged surface. In Connecticut the comparatively steeply sloping Fall Zone pene-

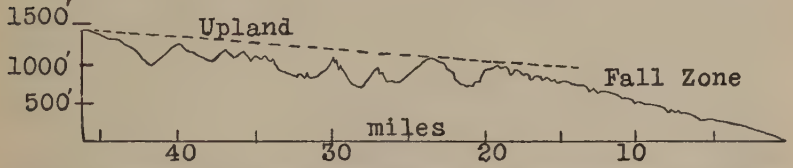


Fig. 9. Reduced profile showing the slope of the upland and Fall Zone peneplanes.

plane forms the shoreline, and if irregularity of shoreline is entirely dependent upon the slope of the submerged peneplane, the difference between the two coasts may be thus explainable. But the subject will bear some discussion. If two sheets of corrugated paper representing dissected peneplanes are imagined to intersect a horizontal plane representing sealevel at different angles, it will be clear that the line of intersection formed by the more gently sloping sheet will be the more uneven. This would seem to prove that the difference in slope of the submerged surfaces is an important factor. Unfortunately, however the analogy between the corrugated paper and the dissected peneplanes cannot be carried very far. The chief valleys passing through the Fall Zone peneplane in Connecticut such as the Thames, the Housatonic, and the Connecticut were made after it was tilted, and their profiles have no tendency to be parallel with the peneplane but are much more gentle in slope. The steeper slope of the Fall zone surface has here no effect tending toward a more regular shoreline, and these valleys drowned form estuaries comparable

[1]A peneplane is an "almost plane" erosional surface, an area of low relief worn down almost to sealevel by the combined action of weathering and erosion working through a long period of time. The peneplanes of New England are no longer found in the position in which they were formed.

[2]Sharp, H. S., "The Fall Zone Peneplane", Science, n.s. Vol. LXIX, pp. 544-545, 1929.

in size with those of Maine. From this and from theoretical considerations it seems probable that the drowning of two peneplanes having different slopes but dissected by streams graded with respect to original sealevel will form estuaries of approximately equal magnitude and shorelines of about the same degree of irregularity.

In the case of many minor southward flowing streams, however, it seems probable that the analogy between the corrugated paper and the dissected peneplane may hold. These streams have their sources upon the surface of the Fall Zone peneplane, and while they have cut deeply into it, they have not attained the low gradients of the major streams mentioned before. For this reason their profiles tend to be more nearly parallel with the slope of the peneplane furnishing a case similar to the tilted corrugated paper in which steepness of slope of the submerged surface is important. Such streams on the Fall Zone peneplane in Connecticut are comparable with the example of the steeply sloping corrugated paper forming a fairly even line of intersection, while similar streams on the Upland peneplane in Maine furnish an example comparable with the gently sloping corrugated paper with its uneven line of intersection with the horizontal plane. Although it thus appears that the regularity of shoreline increases with the steepness of the submerged peneplane in the case of these minor streams, it is doubtful whether they are frequent enough to prove an important factor in determining the difference between the Maine and Connecticut coasts. Their influence is probably very much overshadowed by the large streams previously mentioned, where the size of embayment and irregularity of the shoreline is independent of the slope of the submerged surface.

If a peneplane slopes very steeply any regional irregularities such as the great undulating swells, which may be caused by uneven uplift during tilting, will have a minimum effect in causing coastal irregularity, and no matter how greatly the surface may be dissected later, it will be found that the outer headlands possess a nearly straight or gently curved alignment. The submergence of a steeply sloping peneplane will thus tend toward regularity of outer headlands, but it will have no effect upon the distance to which individual estuaries may penetrate into the land. Nevertheless this is a tendency toward greater regularity of shoreline, and it may have some effect on the Connecticut coast, where the closer alignment of the headlands helps in making the shoreline more regular than that of Maine.

In conclusion, it must be admitted that although there is no room for doubt concerning the greater steepness of the submerged surface in Connecticut, it is difficult to apprise its importance as a cause in making that coast more regular than that of Maine. It seems probable that the greater slope of the Fall Zone peneplane is partly responsible for the more regular coast of Connecticut,

but its importance is greatly subordinate to a cause to be discussed in succeeding paragraphs.

6. Differences in glacial erosion and deposition could cause the difference in irregularity, but the shorelines of the two states are so essentially alike in respect to the amount of glacial erosion and deposition that has taken place along them that the difference in irregularity can scarcely be laid to this cause.

7. Finally to be considered is the possibility that there may have been a difference in the stage of dissection of the landforms at the time of submergence. It is evident that, although the texture may be the same, the more advanced the stage of dissection of a landform becomes the more irregular shoreline it will form upon submergence. Then if the Upland peneplane forming the submerged surface in Maine can be shown to be more dissected than the Fall Zone peneplane, the submerged surface in Connecticut, the cause for the difference in irregularity of the two shores may be found.

Barrell[1] mentioned that "the region (southern Connecticut) is physiographically younger for some distance back from the coast" and a study of the profiles previously mentioned in this chapter shows that the Fall Zone peneplane is indeed very much less dissected than the Upland peneplane. The difference in dissection is so marked that the peneplanes could usually be distinguished on that basis alone without referring to the difference in slope. This difference in the amount of dissection between the two peneplanes, which is well shown in Fig. 9, is believed to be sufficient to cause the great difference in the irregularity of the shorelines of Maine and Connecticut. In Connecticut the little dissected Fall Zone peneplane forms a fairly even shore, in Maine the much more dissected Upland peneplane forms a very irregular shoreline.

Summary

In the discussion here concluded the author has drawn attention to the singular difference in irregularity between the shorelines of Maine and Connecticut. The shores of both states have originated through the submergence of former landmasses, yet the shoreline of Connecticut is strikingly more regular than that of Maine. Seven hypotheses have been discussed in an effort to learn the cause of the difference. Four of these were easily dismissed, while a fifth concerning the possible effect of the deeper submergence of the Maine area proved difficult of analysis, although it is probably not an important factor. Finally the effect of a steeper sloping submerged surface in Connecticut was judged to be of some importance, while the major cause of the difference was decided to be the relatively small amount of dissection of the submerged peneplane in Connecticut, when compared with that in Maine.

[1]Barrell, Joseph, "The Piedmont Terraces of the Northern Appalachians", A. J. S. 4th Ser., Vol. XLIX, p 248, 1920.

CHAPTER IV.

THE PHYSIOGRAPHIC HISTORY OF THE SHORELINE.

To the physiographic history of an area the geology is important only in so far as it has a direct effect upon the surface topography at present. Thus many formations and events of great geologic significance may be scarcely mentioned or completely ignored, if their presence is not clearly reflected in some topographic feature at the surface. The science of physiography, or geomorphology as many prefer to call it, seeks to explain the surface features of the earth, and in this chapter the events of significance in the physiographic history of the shoreline area of southern Connecticut will be set down in chronologic order.

PRE-MESOZOIC.

1. During Pre-Cambrian and Palaeozoic times Connecticut in common with all New England was passing through a complicated series of events, which were to give it a structure of infinite complexity. Apparently no surface features existing at that time are extant in the present topography of Connecticut, but through endless ages series after series of sediments were deposited, injected by liquid magmas, and under the influence of heat and mountain-making pressure were folded, broken, and profoundly altered until often their original character can no longer be recognized. Such processes form complex mountains often of chaotic geologic structure, and the only semblance of unity in the rocks underlying the New England Upland Province seems to be the general presence of a north or northeast trend in the direction of the rock structure. Upon this complex, destructional forces with few exceptions have been at work through all subsequent geologic time.

Triassic.

2. After the end of the Palaeozoic the area possessing this complex structure was in part at least worn down to a peneplane, for the next event of importance, the deposition of Triassic clastic sediments, seems to have taken place upon a fairly level crystalline basement.[1] Simultaneously with the deposition upon this basement of great thicknesses of Upper Triassic shales and sandstones occurred the intrusion and extrusion of massive layers of trap. Although the difference in origin of these great sheets of igneous material is of geological importance, it is interesting to note that it is of no physiographic significance, since the surface

[1]Davis, W. M., "The Triassic Formation of Connecticut," U. S. G. S., An. Rpt. 18, pt. pp. 1-192, pp. 19-26, 1898.

forms resulting from rocks of either type of origin are similar. Faulting occurred throughout the period of deposition and was pretty well distributed over the area in which sedimentation took place. By means of great north-south boundary faults, which to this day separate the sediments from the crystallines on the east, the net result in Connecticut was to lower all the strata differentially and give them a regional dip of 5 to 20 degrees east. With this added complication the complex mountains mentioned in the previous paragraph form the solid block from which the forces of destruction have carved Connecticut.

The Fall Zone Cycle.

3. After this period of disturbance an era of great quiet prevailed, and for countless centuries the forces of erosion worked their will upon the mountains. Gradually their efforts succeeded, and the highlands disappeared to be almost imperceptibly replaced by a low and rolling country standing but a few feet above sea-level. Regardless of geologic structure and differences in rock hardness the peneplane stretched an almost unbroken surface across the great faults which separate the sediments from the harder crystallines. The erosion of this time removed great thicknesses of Triassic rock, while that which is still preserved in the Connecticut Valley Lowland owes its presence to the faulting which dropped it below the baselevel of erosion. The extensive surface formed at this time is the one to which the author has applied the name Fall Zone peneplane.

The Burial of the Fall Zone Peneplane.

4. At last the long period of quiet drew to a close, and the great peneplane was slowly covered by thick series of deposits derived from the waste of the land. In Connecticut the beds, which were deposited upon the former land surface, were apparently of Upper Cretaceous age and were probably largely marine in origin, but they were considerably older further south. There the beds contain many fossils of plants and land animals showing that they were not deposited beneath the sea. Due to their characteristic development near the Potomac River, these beds, which are believed to have been formed as great delta plains by the heavily loaded rivers flowing from the gradually rising land to the west, are known as the Potomac Series. Since they are much older than the oldest beds, which covered the Fall Zone peneplane in Connecticut, it can be judged that the burial was progressive with the old erosion surface exposed in the north long after it had been covered in the southern area. Thus erosion could continue in the north long after the surface was buried in the south,

and for that reason it might be expected that the northern part of the peneplane would be even more level and perfect than the southern. Nevertheless no such difference has been detected and probably does not exist, because the Fall Zone peneplane was very perfect when burial began, and the much longer period of time during which the northern part was exposed to erosion did not suffice to change it further.

The earth movement which terminated the Fall Zone cycle was not uniform throughout: toward the north and northwest it resulted in uplift, while seaward of an axial line more or less parallel and coincident with the present Fall Line the surface was depressed to near or below sealevel. In Connecticut the depression carried the peneplane below sealevel. Thus toward the north a new cycle of erosion was started by the streams rejuvenated through uplift, and the Fall Zone surface began to be destroyed, while the waste from this destruction with the aid of marine sediments buried the lowered surface in the south.

When the submergence in the Connecticut area had reached its greatest extent, the streams once emptying into the ocean considerably to the south found that their mouths had moved to the north with the advancing shoreline, which was probably even more irregular than that of today.

The New England Upland Cycle.

5. Near or at the end of the tilting, which started the destruction of the Fall Zone peneplane toward the northwest and caused the burial of its southeastern part, there occurred a new movement of the earth's surface resulting in uplift. The exact character of the uplift cannot be ascertained, but it initiated the erosion of the newly deposited continental and marine sediments southeast of the former shoreline and started a period of denudation which was to end, when these and the resistant crystallines to the northwest were worn nearly to baselevel and a new peneplane was formed.

Coincident with the movement raising the land above sealevel the shoreline was forced to retreat toward the southeast, and the streams extended their lower courses across the young coastal plain thus exposed.

Due to uneven deposition the surface of this plain, just lifted above sealevel, must have been slightly irregular, and the streams naturally adjusted themselves to these irregularities in finding their way to the sea. North of the former shoreline their courses were more or less in accordance with the geologic structure, and they flowed southward in parallel paths subsequent to the strike of the rocks. When they entered upon the unconsolidated deposits of the Coastal Plain, the structure, which had hitherto governed their courses, was buried, and they found themselves on

practically horizontal beds. No differences in rock hardness now directed the streams, and they wobbled uncertainly southward in courses consequent upon the uneven initial surface and the slight seaward slope of the plain. Such streams might easily cut across buried topographic and geologic boundaries of importance.

At this early date the present Connecticut River took the course which with few exceptions it follows to this day. Passing southward upon the Triassic it flowed out across the cover of sediments overlying the Fall Zone peneplane, here wavered and made a very

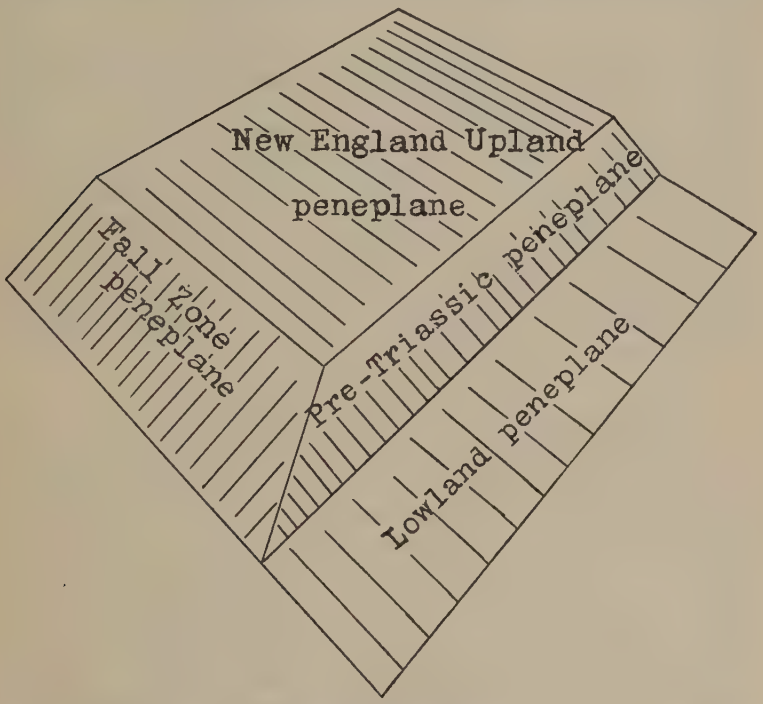


Fig. 10. Block diagram showing the relationship of the four peneplanes west of New Haven.

marked bend to the southeast. When it had cut downward to the peneplane surface, it discovered that it had unwittingly been led into error such as has cost many rivers their heads. For it had set its path away from the soft Triassic rocks onto the hard crystallines choosing not only a more difficult but a longer route to the sea. Hemmed in by the valley walls, it was too late to change the path, which it has been forced to follow through all subsequent time. The great change in direction of the lower Housatonic has been explained in the same manner, while still

farther west the Hudson probably won its course across the Highlands as a result of superposition from the same Coastal Plain cover. Since the great bend where the Connecticut turns to leave the Triassic is at Middletown, the cover must have extended at least that far. For this reason Schuchert in drawing his paleogeographic maps has shown the state submerged to the latitude of Middletown in Late Cretaceous time. According to this explanation the superposition of the streams seems to have taken place originally upon the old Fall Zone surface and not upon the succeeding and younger peneplane, where most writers have placed it.

As the cycle of erosion initiated by the uplift continued, the landmass was worn down almost to baselevel, and another peneplane, the third in this history of the shoreline, appeared. This peneplane, the most extensive of any in New England, impartially beveled all rocks regardless of age and hardness. Not only did it plane the three different groups of rocks, but as indicated in Fig. 10, it intersected two previous erosion surfaces, the Pre-Triassic and the Fall Zone peneplanes. At that time these were buried and evident only as geologic (Fig. 11) and not as topographic boundaries. Today the remnants of the surface resulting from this last great cycle of erosion are known as the New England Upland peneplane.

The Connecticut Valley Lowland Cycle.

6. Another uplift accompanied by tilting terminated the Upland cycle of erosion. The tilting seems to have been toward the southeast, for the Upland peneplane slopes in that direction about 15 feet per mile. The exact amount of warping cannot be determined, but since peneplanes are approximately horizontal when formed, it was probably between 10 and 15 feet per mile. The uplift initiated a new cycle of erosion, and once more the forces of destruction vigorously attacked the surface of the land. Because they were most vulnerable to erosion and nearer the new baselevel, the Coastal Plain deposits were probably removed most rapidly, while the Triassic shales and sandstones being considerably more resistant remained somewhat longer. Nevertheless, when compared with the durable crystalline rocks underlying the present Upland, both were so weak that the areas underlain by them were worn almost to sealevel, while the peneplane on the crystallines was still far from total destruction. No better example of the influence of rock resistance on the length of the physiographic cycle could be found. It would take untold millions of years for the youthful streams of the Upland to wear it down to the level of the peneplane they had already formed on the softer rocks.

This difference in the resistance of the rock has resulted in the survival of two interesting and important physiographic features, which might otherwise be known only through well borings. As the soft Coastal Plain and Triassic sediments were removed, two former land surfaces were partly uncovered. These were the Pre-Triassic[1] and the Fall Zone peneplanes cutting across crystalline rocks so hard that the removal of the protecting cover has not yet allowed erosion to destroy completely the resurrected surfaces. Since erosion had been at work on the Upland for some time before the older surfaces were resurrected, it might be expected that the latter would be somewhat less dissected. This is true of the Fall Zone peneplane, and as Barrell[2] states "the region is physiographically younger for some distance back from

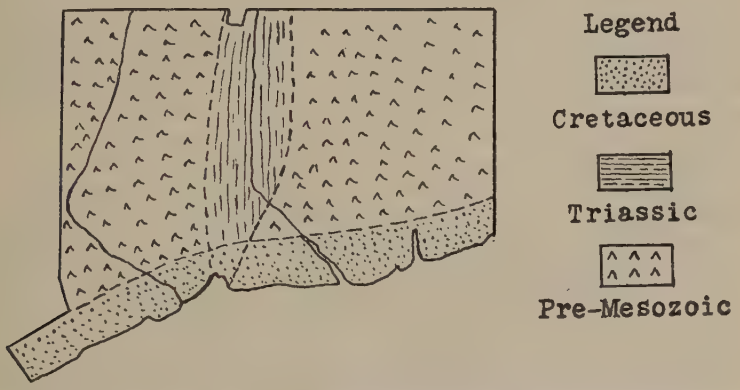


Fig. 11. Geologic map of Connecticut showing major distribution of rocks at end of the Upland Cycle.

the coast." Reference to the profile of Fig. 9 will show that the surface is less dissected within the area covered by the Fall Zone peneplane. This was so noticeable that the two peneplanes could often be distinguished on the basis of dissection alone. In the Adirondack region a similar relationship is said[3] to obtain between the resurrected Pre-Cambrian peneplane and the much younger surface which bevels it. Probably such a relationship is expectable, whenever two peneplanes occur in this manner. In Connecticut, however, the Pre-Triassic surface has been so broken by faults that it is difficult to compare its dissection with that of the Upland. In southeastern New York a similar Pre-Triassic

[1]Davis, W. M., "The Geological Date of Origin of Certain Topographic Forms of the Atlantic Slope of the United States," Geol. Soc. Amer., Bull. Vol. II, pp. 545-586. See p. 549 1891.

[2]Barrell, Joseph, "The Piedmont Terraces of the Northern Appalachians," Amer. Jour. Sci., 4th ser., Vol. XLIX, p. 248, 1920.

[3]Oral communication from Professor E. M. Lehnerts of New York City.

surface should occur on the eastern side of the Hudson; at places the slope from the Upland down to the River is so even and extends so nearly parallel to the dip of the Newark Series in New Jersey that the presence of the Pre-Triassic peneplane is very strongly suggested. For lack of detailed knowledge no statement can be made concerning the amount of its dissection, but the rectilinear[1] eastern shore of the lower Hudson suggests the submergence of a fairly undissected surface.

Topographic features formed in this manner by the intersection of two peneplanes, one of which has been resurrected, have been called morvans by Davis[2] and the term is too useful to be abandoned in spite of a recent criticism,[3] which states that the process is too complicated to be effectively designated by a single word. Much of the interest attached to the physiographic history of Connecticut is due to the presence of the two morvans formed by the intersection of the resurrected Pre-Triassic and Fall Zone peneplanes with the Upland peneplane. In addition a more unusual feature, the intersection of two resurrected peneplanes, may occur on the western wall of the Triassic Lowland just southwest of New Haven, where anyone capable of visualizing the intersection of two planes may see that a line sloping downward toward the southeast should mark the intersection of the eastward-sloping Pre-Triassic and the southward-sloping Fall Zone peneplanes. On Manhattan Island the two peneplanes may form a similar line of intersection sloping toward the southwest because of the westward slope of the Pre-Triassic surface there. In neither New York or Connecticut have these lines been idenified, perhaps for lack of search, but it is quite likely that they have been entirely removed by erosion. A matter of purely theoretical interest is the intersection of the two morvans, which at one time must have occurred at a point where the three peneplanes come together as shown in Fig. 10.

With the exposure of the Fall Zone surface it becomes possible to approximate the amount of tilting it received in the uplift, which preceded the Upland Cycle. In Connecticut the Upland peneplane was tilted 10 to 15 feet per mile toward the south, while the Fall Zone slopes in that direction about 50 feet per mile It appears then that the Fall Zone peneplane was tilted about 35 feet per mile in the uplift which raised its northern part high enough to permit destruction by later erosion. These figures do not take account of possible later differential movements, which might change them somewhat.

---

[1]Johnson, D. W., "The New England-Acadian Shoreline" 608 pp. John Wiley, New York, 1925, p. 31.

[2]Davis, W. M., "The Relation of Geography to Geology," Geol. Soc. Amer., Bull. Vol. 23 pp. 93-124, p. 117, 1912.

[3]Campbell, M., "Geographic Terminology," Ann. Assoc. Amer. Geog., Vol. XVIII, p 31, 1928.

When the orderly processes of erosion were once more interrupted by diastrophic movement, their work was still far from completion. Although the Triassic rocks were worn nearly to sea-level, the Lowland peneplane formed at this time was never comparable with the three great peneplanes, which had already left their imprint upon the Connecticut landscape. Long Island Sound had not yet come into existence and as shown in Fig. 12, the surface of the Lowland peneplane was continued in a Coastal Plain, which extended along the entire southern edge of the State in a belt about as wide as the present Sound. After passing through its gorge in the Eastern Upland the superposed Connecticut flowed across the tilted Coastal Plain beds into the Atlantic carrying with it all the debris it had gathered from the Triassic Lowland. The removal of the Triassic rocks had formed the Connecticut Valley Lowland essentially as it is today, and the difference in elevation between the concordant hilltops of the Lowland and the Upland surface may be taken as the measure of the amount of uplift which closed the Upland and started the Lowland cycle of erosion.

The Sound Valley Cycle.

7. The Lowland cycle was terminated by a movement, by which the land was once more lifted in reference to the sea. Rejuvenated by the uplift, the streams vigorously renewed the work of erosion and within a comparatively short time etched out some of the most prominent features of the present. The exact course taken by the Connecticut River of that time south of its present mouth is very problematical; Veatch[1] believed it to flow southwestwardly through the Coastal Plain across what is now Long Island to join that part of the Hudson channel[2] which is now deeply submerged. Dana[3] believed the River to flow southward across the present site of the northern fluke of Long Island in the direction of the present Peconic Bay, while Fuller[4] seems to believe that its course passed eastward somewhere between the present Fishers Island and Greenport, Long Island. Although details concerning the exact direction of flow of the Connecticut are lacking, it has long been recognized that the River may have at that time followed a course quite comparable to the present Delaware. Like the latter stream it may have closely followed the contact of the sedimentary and crystalline rocks for some distance, before it turned to cut directly across the Coastal Plain

[1]Veatch, A. C., "Underground Water Conditions of Long Island," Prof. Paper U. S. G. S., No. 44, pp. 28-32, 1906.
[2]Spencer, J. W., "The Submarine Great Channel of the Hudson River," Amer. Jour. Sci., 4th ser., Vol. XIX, pp. 1-15, 1905.
[3]Dana, J. D., "Long Island Sound in the Quaternary Era, with Observations on the submarine Hudson River Channel," Amer. Jour, Sci., 3rd ser., Vol. 40, pl 425-437, 1890.
[4]Fuller, M. L., "The Geology of Long Island, N. Y." U. S. G. S. Prof. Paper 82, p. 58, 1914.

to the ocean. On the other hand it may have flowed in an inherited course directly across the Coastal Plain, while a number of subsequent tributaries were developed parallel with the trend of the bedding. In any case the final result was much the same, for as shown in Fig. 13, the streams eroded an inner lowland, 20 miles broad in places, which separated the cuesta of Cretaceous rocks from the Connecticut crystalline oldland. When the inner lowland had reached its greatest extent, that part of the Lowland peneplane which was on the Coastal Plain was destroyed except for possible remnants on the top of the Cretaceous cuesta, and a new erosion surface, which might be called the Sound Valley, had developed. The uplift initiating this erosion cycle naturally started a further stripping of cover from the Fall Zone peneplane exposing a belt which having been exposed to erosion for a shorter time than ony other is comparatively little dissected. On the pres-

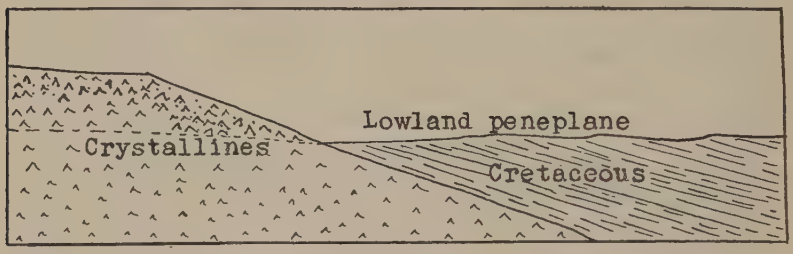


Fig. 12. North-South cross-section showing Connecticut at the end of the Lowland Cycle.

ent Triassic Lowland of Connecticut, however, the uplift had no more effect than to entrench the streams below the Lowland peneplane level, which may still be seen in considerable perfection. The preservation of the peneplane in the Lowland seems to be due not only to the greater resistance of the Triassic clastics but to their peculiar situation within the encircling crystallines. By far the greatest part of the Lowland drainage was to the Connecticut, the surface of which, at Middletown, where it entered the crystalline gorge, constituted a local base level for most of the Lowland streams. These were unable to cut downward more rapidly than the Connecticut, and since the latter was held up where it crossed the crystallines, the removal of the Triassic was greatly retarded. Conditions on the small streams flowing southward out of the lower end of the Triassic were probably similar, since it seems likely that the southwardly converging walls of the Upland may have met a short distance south of New Haven to form a complete ring of protection, which, acting as a local base-level, prevented the removal of Triassic material with a rapidity

comparable with that of the Cretaceous. At the same time it must be clearly recognized that the existence of a local baselevel is not necessary to explain the difference in elevation between the Sound Valley and the Lowland peneplane. Had there been no rock protection the difference in resistance between the weak Cretaceous sands and gravels and the Triassic consolidated sandstones and shales would suffice to explain the difference. The harder Triassic rock would normally stand above the Cretaceous unless the work of erosion had been very complete. In either case, however, the development of the Sound Valley is seen to be due to a different and later cycle of erosion than the Lowland. For one or both of these reasons the Connecticut Valley Lowland today stands several hundred feet higher than the inner lowland trench, a difference of no mean economic importance. (Fig. 13).

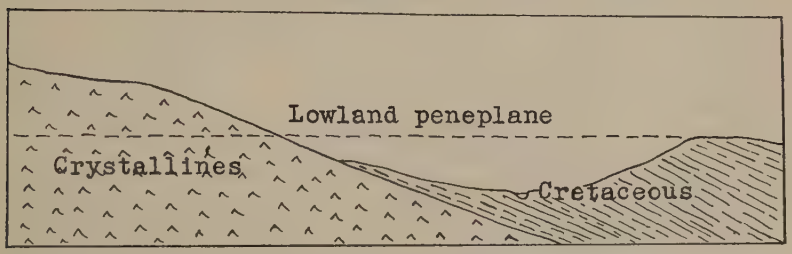


Fig. 13. North-South cross-section showing Connecticut and Long Island at the time of formation of the Sound Valley.

The Regime of Ice.

8. The cutting of the inner lowland was interrupted by an event, which has been of great importance in giving the Connecticut shoreline an individuality apart from that of any neighboring state. Due to some unknown cause the climate became cooler, and Connecticut in common with all the northeastern United States and Canada was covered by a great ice sheet, a continental glacier, comparable with the ice caps now covering most of Greenland and Antarctica. The climatic change may have been surprisingly slight, for all that was necessary to cause glaciation was to have a little more snow fall each winter than could melt away in the following summer. Under the impulse of gravity, the ice sheet, which may have been two miles thick in places, moved slowly outward from its center of accumulation carrying with it a tremendous amount of debris gathered from the country over which it had passed. The debris, much of which was frozen in the bottom of the ice or pushed along by it, acted as a gigantic rasp and scratched long grooves and striae in the bedrock parallel with the direction of glacial movement. In southern Connecticut

these striae together with boulders left by the ice far south of their occurrence as bedrock indicate that the movement was toward the south and southeast.

The great moraines of unsorted debris dropped at the southern terminus of the glacier are not found on the Connecticut shore, for the advancing ice front passed southward beyond the present boundaries of the State crossing the inner lowland and climbing over the landward-facing scarp of the cuesta developed on the Cretaceous rocks of the Coastal Plain. As shown in the cross-section (Fig. 14) the advance was finally arrested on the gentle, seaward-facing backslope of the cuesta. Here the ice front remained for a long time, although the presence of two terminal moraines indicate that it did not remain in one position the entire time. While the glacier was depositing the northern and later moraine, it terminated in an ice front, which, if in existence today,

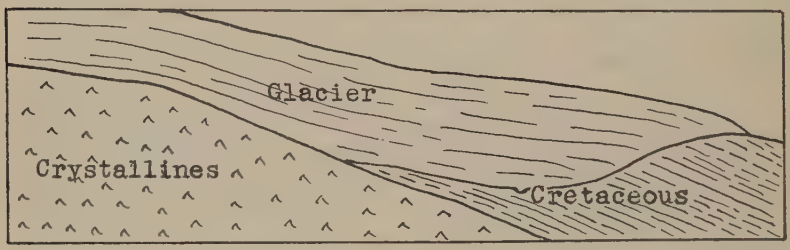


Fig. 14. North-South section of southern Connecticut and Long Island during glaciation.

would follow a line passing from the northern fluke of Long Island through Fishers Island to Watch Hill and the southern coast of Rhode Island thence to the Elizabeth Islands, and north toward Plymouth; at that time the ice front would entirely miss Connecticut, although the jumbled mass of unconsolidated debris, which characterizes the terminal moraine, was dropped no further away than the Rhode Island shore of the Pawcatuck River.

Before the coming of the ice the surface was probably covered by a thick mantle of soil and decomposed rock, such as occurs in the unglaciated Piedmont section of the South today. The advancing ice scraped away practically every bit of this material, for it has been found in only a few localities in Connecticut. All the material collected by the glacier was not carried to the terminal moraine, but much of it was strewn upon the surface over which the ice advanced and retreated. Today this glacial drift forms the soil of all the glaciated states including Connecticut. The drift is distributed very unevenly; in places the rounded and striated surface of the bedrock is exposed or very thinly covered,

while a short distance away the soil may be 20 feet or more in thickness. The thickness, however, is probably rarely comparable with that in the terminal moraine.

The work of erosion and deposition was not the only important result of glaciation. The weight of the ice sheet was enormous, and after it had covered Connecticut for some time, the entire region began to sink beneath it. No one can say for certain that this was the cause of the depression of the land, but it seems true that the movement was greatest where the ice was thickest and consequently heaviest. The amount of submergence occurring at this time cannot be exactly determined, but when the ice disappeared the inner lowland was below sealevel, and the scarp and backslope of the cuesta were separated from the oldland by the invading waters. As shown in Fig 15, these are the waters of Long Island Sound, while Long Island is that part of the cuesta

Fig. 15. Structure section showing present relationship between Long Island and southern Connecticut.

and glacial drift which remained above sealevel. In many places the Sound is from 200 to 300 feet deep, and since it was developed largely by subaerial erosion, its bottom must have stood at least that much higher above sealevel than at present. This indicates a maximum submergence of at least 300 feet, but as stated by Martin[1] some of this depth is probably due to tidal scour, since the deepest places are located at the points where greatest scour might be expected. With this flooding the geography of the southern Connecticut region became practically that of today.

Postglacial Changes of Level.

9. Only one small diastrophic movement remains to be recorded in the physiographic history. When the ice had withdrawn far enough to allow a temperate climate, vegetation immediately began to flourish. Along the shores of protected bays salt marsh plants began to grow exactly as they grow today. Certain species

[1]Martin, L. H., "The Geology of the Stonington Region, Conn.," Conn. Geol. and Nat. Hist. Surv., Bull. 33, p. 69, 1925.

were only able to live within the narrow vertical limits between high and low water, while others could thrive only immediately above the high tide level. Today borings and excavations in the marshes bring to light plants of these species many feet below sealevel, where with few exceptions their presence can only be explained by postglacial submergence, a theory first proposed by B. F. Mudge[1] and later greatly elaborated by C. A. Davis. From top to bottom the marsh deposits are very uniform in composition being formed largely of the matted particles of dead vegetation in the place of their origin. Thus the submergence must have been so gradual that the slow deposition of dead plants was always able to maintain the marsh surface at a level suitable for the growth of a high tide flora. From the depth below sealevel of these marsh peat deposits Fuller[2] has estimated that the postglacial movement was not over 25 feet, while Johnson[3] who places it at over 20 feet, points out that the total movement may have been greater than the present depth of the peat. In the Stonington region of Connecticut Martin[4] on entirely different evidence has placed the depression at about 20 feet.

On the other hand no satisfactory evidence of deeper submergence has been found. As stated by Martin[5] glacial till extends to the limits of storm wave action along the entire Connecticut coast; it seems reasonable to infer that this would have been removed and redistributed by wave action had the sea ever stood higher than at present along the shore in postglacial times, although this is not necessarily true, if emergence has been rapid. The general lack of any clear cut marine forms of erosion or deposition above the present sealevel, even in situations where they are most to be expected, seems to be a fair reason for doubting that the sea has ever stood higher than now on the Connecticut coast in postglacial times. If, as seems sure, this State in common with most of northeastern North America was upwarped in postglacial time, the axis of movement must have been such that any uplifting tending toward emergence in southern Connecticut was more than offset by the rise in sealevel caused by the waters from the melting of the great ice sheet.[6] In a number of papers, however, Fairchild[7] has indicated his belief that the Connecticut shore has suffered a submergence of 150 to 200 feet greater than at present.

---

[1]Mudge, B. F., "The Salt Marsh Formation of Lynn, Mass.," Essex Institute, Proc., Vol. 2, pp. 117-119, 1862.

[2]Fuller, M. L., "The Geology of Long Island, N. Y.," U. S. G. S. Prof. Paper 82, p. 216, 1914.

[3]Johnson, D. W., "The New England-Acadian Shoreline," pp. 584-585.

[4]Martin, L. H., "The Geology of the Stonington Region, Conn.," Conn. Geol, and Nat. Hist. Surv., Bull. 33, p. 67, 1925.

[5]Martin, L. H., ibid., p. 68.

[6]Antevs, E. A., "The Last Glaciation," Amer. Geog. Soc. Research Series, No. 17, pp. 83-85, 1928.

[7]Fairchild, H. L., "Postglacial Uplift of Southern New England," Geol. Soc. Amer., Bull. 30, pp. 597-635, 1919, p. 616. See also by the same author, "Pleistocene Marine Submergence of the Connecticut and Hudson Valleys," Geo. Soc. Amer. Bull. 25, 219-242, 1914.

More recently Johnson[1] has drawn attention to the unsatisfactory nature of much of the evidence in favor of deeper postglacial drowning while Goldthwaite[2] and Hörner[3] find no evidence in their areas which would cause one to suspect deeper submergence in southern New England. Flint[4] after a study of the terraces of the Connecticut River Valley has decided that they are not of marine origin and hence cannot be used as a proof of higher sea-level. Nevertheless the problem is still far from solution, although it seems to the author unlikely that the Connecticut coast has been more deeply submerged.

Is the Shore Still Sinking?

With the postglacial submergence of approximately 20 feet, which some authorities believe to be continuing at the present time, the diastrophic history of the shoreline probably ends, although the idea that subsidence still amounts to one or two feet per century is very widespread among the public. It cannot be denied that some small areas have been submerged within the area of the northeastern United States during the past 300 years, but the drowning of small areas due to purely local causes must be distinguished from regional subsidence on a large scale caused by a change in the relative level of land and sea due to movements within the earth. The chief evidence upon which it is sought to prove modern subsidence is the finding of submerged fresh water or land vegetation such as tree stumps in places where they have been killed by the invasion of salt water, or the presence in their original location, which was above the former level of the sea, of various relics of man at points now below high tide.[5] Old forests, the stumps of which are now far below high tide level,[6] do undoubtedly indicate a change in the relative elevation of land and sea, but they do not demonstrate a change within the time since the first white settlements were made in New England. Many cases of the drowning of forests by invading salt water have been recorded during the past three centuries, and if these are not capable of other explanation they must be regarded as evidence of historic subsidence. After long study Professor Douglas Johnson[7] believes that such cases can be explained by local changes in the form of the shoreline resulting in an increase of the high

[1]Johnson, D. W., "The New England-Acadian Shoreline," p. 133, 1925.
[2]Goldthwait, J. W., "Physiography of Nova Scotia," Geol. Surv. of Canada, Memoir 140, p. 150. 1924.
[3]Horner, N. G., "The Late Glacial Marine Limit in Massachusetts," Amer. Jour. Sci., vol. XVII, pp. 123-145. 1929.
[4]Flint, R. F., "Pleistocene Terraces of the Lower Connecticut Valley," Abst. Geol. Soc. Amer. Bull. 39, pp. 216-217. 1928.
[5]Davis, C. A., "Some Historical Evidence of Coastal Subsidence in New England," Abstract with discussion Geol. Soc. Amer., Bull. 25, pp. 61-63. 1914.
[6]Goldthwait, J. W., "Physiography of Nova Scotia," Canada Dept. of Mines, Memoir 140, pp. 155-161. 1924.
[7]Johnson, D. W., "Botanical Phenomena and the Problem of Recent Coastal Subsidence," Bot. Gaz., LVI, pp. 449-468. 1913.

tide level. Not only do such changes in the shoreline cause a local rise in tide level simulating subsidence, but they may also cause a lowering of high tide level allowing fresh water vegetation to occupy an area formerly covered by salt marsh thus yielding a false appearance of elevation of the land. Changes of the latter type being less striking are not so readily apparent to the casual observer, and for that reason few cases have been reported.

An illustration of the manner in which a small change in shoreline may cause apparent subsidence is best afforded by a consideration of high tide level within and without a large lagoon separated from the ocean by a bar through which passes a small inlet. When the tide is at its highest in the ocean a swift stream of water will be flowing through the inlet into the lagoon. Due to the small size of the inlet and the great volume of water necessary to raise the lagoon level to that of the ocean, the tide in the latter will begin to fall long before the water level in the lagoon reaches the level of high tide in the ocean. Naturally then the inflow of water from the ocean will cease before the lagoon is filled and high tide in the latter will never be as high as that outside the bar. This means that fresh water vegetation may grow on the inside of the bar and on the entire shore of the lagoon down to the high tide level of the lagoon at a point considerably below the ocean high tide level. If the inlet is now significantly enlarged or the bar is breached by a storm, much more water will flow into the lagoon from the ocean at high tide, the high tide level of the entire lagoon will be raised, fresh water vegetation and land plants will be flooded by salt water causing their death, the lagoon may soon be encircled by a fringe of dead stubs, and one more fictitious evidence of coastal subsidence may be reported to science. Careful checking will probably show that it is merely local submergence. In a similar manner many cases of the drowning of the evidences of human occupation, which must have originated above high tide level, may be explained.

Among other evidence put forth in favor of historic subsidence is the lower surface elevation of reclaimed tidal marshes in comparison with the high tide level in unreclaimed areas immediately adjoining. This relationship is especially well shown in the Bay of Fundy region, where Goldthwaite[1] after consideration of all the evidence agrees with Johnson that historic subsidence is not indicated. Many of these marshes have been dyked and drained for two centuries or more, and the reclaimed area is often found to be several feet lower than the wild marsh outside the dykes. On the assumption that a rise of sealevel outside the dykes has allowed the wild marsh to grow higher, this has been taken to indicate a subsidence equal to the difference in elevation between

[1]Goldthwait, J. W., "The Physiography of Nova Scotia," Canada Dept. of Mines, Memoir 140, pp. 150-161. 1924.

the two surfaces since the building of the dykes. As shown by Johnson[1] this assumption is unnecessary, and the difference in elevation is due to a compacting of the material in the reclaimed marsh after the removal of a large percentage of the water content. That the surface of the wild marsh has not been elevated by later additional growth is shown by its correlation with the surface deposits of the reclaimed marsh proving that both were deposited at the same time.

It is a common occurrence to find the top of a peat layer underneath the seaward side of a sand bar considerably lower than the surface of the marsh within the lagoon formed by the bar. This cannot be taken as an evidence of subsidence since the building of the bar but is due to the compacting of the marsh under the weight of the sand. As indicated by correlation[2] of the deposits the top of the peat was once on the same level as the marsh and has sunk under the weight of the bar. The partial burial by the marsh of structures and deposits of human origin has been taken to indicate subsidence, but with the above in view it is evident that all or many of these cases may be due merely to the sinking of the marsh under the weight of the structure.

This discussion could be elaborated indefinitely, but with the consideration of one more fallacious argument in favor of historic subsidence, will be closed. It is very often said that the continuation of erosion on a coast indicates progressive subsidence. Such is not the case. As long as waves can attack a landmass they will erode it until at last it may even be worn below sealevel. If erosion continues, as it does, on the shore of lakes where there is no possibility of change in level, it can certainly continue without subsidence on the shore of the ocean where the waves are much larger.

With the postglacial submergence of approximately 20 feet then, movements of the land and sea seemed to have ceased, the waters of Long Island Sound reached their present elevation in relation to Connecticut, and it becomes clear that few events of the past have failed to leave some evidence of their occurrence on the shoreforms of the present. Since then the forces of marine erosion have been ceaselessly at work; here eroding material, there depositing, they have infinitely modified the details of the shore. Their work is going on this minute, as it was yesterday, and will be tomorrow. Their tireless efforts are of more than academic interest, for not only are the changes they accomplish interesting in themselves, but they are often of the greatest economic importance to mankind.

---

[1]Johnson, D. W., "The New England-Acadian Shoreline," pp. 540-545.
[2]Ibid., pp. 528-530.

Marine Terraces.

Before bringing to a close this chapter on the development of the surface features of southern Connecticut it will be of interest to refer briefly to a somewhat different interpretation of the history of the Upland, which, however, does not necessarily conflict with that already given. This interpretation developed by the fertile brain of Professor Joseph Barrell of Yale University is chiefly known through a posthumous publication[1] edited by H. H. Robinson, and it is to be regretted that Professor Barrell did not live to do further work upon this important subject. As set forth in a bulletin of this Survey[2] Barrell believed that the Upland surface did not ascend evenly but in a series of broad steps with treads five to ten miles wide and rises about 200 feet high. From this he argued that after the formation of the peneplane it had undergone marine erosion at a number of different levels resulting in the formation of broad terraces with the rises indicating the position of seacliffs and hence old shorelines. Due to Barrell's influence perhaps too much emphasis has been placed upon the terraces and their origin, and the importance of the Upland and Fall Zone surfaces upon which the terraces, whether of wave or other origin, have been formed, has lacked proper recognition.

In conclusion it must be stated that some investigators doubt the existence of the terraces, and future work on this problem will be awaited with interest.

Summary.

In the discussion here concluded the author has tried to set down in chronologic order the important geologic events, which have had a direct influence upon the present shoreline of Connecticut. Many points of great importance geologically are not mentioned, since they have not had, so far as analyzable, any effect in shaping the shoreline. For example, Connecticut apparently does not show any evidence of the very intricate series of changes in the relative level of land and sea, which Fuller[3] has described as occurring in Long Island during the Pleistocene, and they have not been discussed here. It is believed, however, that the history of the shoreline as here given will not be found inconsistent with that of surrounding areas.

---

[1]Barrell, Joseph, "The Piedmont Terraces of the Northern Appalachians", Amer. Jour. Sci. 4th Ser., Vol. XLIX, pp. 227-258, 327-362, 407-428, 1920.

[2]Barrell, Joseph, "Central Connecticut in the Geologic Past," Conn. Geol. and Nat. Hist. Surv., Bull. 23, pp. 17-19, 1915.

[3]Fuller, M. L., "The Geology of Long Island", U. S. G. S. Prof. Paper 82, pp. 217-219, 1914.

CHAPTER V.

POSTGLACIAL CHANGES AND THE PRESENT SHORELINE: THE HARD ROCK SHORELINE.

When marine erosion started with the sea at its present level in relation to the land, the initial outline of the shore presented to its attack was entirely the result of the geologic events, the history of which has been traced in the preceding chapter. The changes of shoreline, which erosion and deposition have since caused and are causing, and the present form of the shore remain for discussion as the final stage in the physiographic history of the southern Connecticut area. The many changes which have occurred, are geologically unimportant, but they have modified the shoreline considerably in detail, while those which have occurred in modern times are often economically important to man.

Comparison of Connecticut and Rhode Island Shores.

Due to the influence of geology on topography and the influence of topography on human affairs, it not infrequently happens that geologic boundaries form the boundaries of nations and states. Such a boundary line is the Pawcatuck River (Fig. 22), which separates southeastern Connecticut from southwestern Rhode Island. Forced aside by the terminal moraine, the River takes a circuitous route to the sea dividing the shore line very precisely into two very distinct types. East of the River's mouth in Rhode Island the initial shorelines followed the irregularities of the later and more northerly terminal moraine, which, as has been previously stated, swings northeastward from the northern fluke of Long Island through Fishers Island to Rhode Island, where it is closely followed by the present shore. The moraine is composed of boulders of all sizes mixed with clay like raisins in a pudding. Since this material is uncemented, it is easily eroded, and shorelines in it have suffered extensive and even alarming changes within the memory of man. Thus in Rhode Island the agents of marine erosion have altered the shore so extensively that it differs in a very striking manner from the Connecticut shore immediately to the west. The Rhode Island shore is almost straight and sweeps from cliffed headland to cliffed headland in long sand beaches, which separate shallow lagoons from the ocean. The straightness is due entirely to the work of erosion and deposition and is in marked contrast to the Connecticut shore, where the material composing most of the original shorelines is so resistant that the sea has been unable to accomplish more than a slight amount of straightening. The present character of the shorelines of the two areas affords a good example of the influence of rock resistance upon the rapidity of marine erosion;

originally both shorelines must have been about equally irregular. Today Connecticut's shore composed quite largely of hard rock is infinitely more irregular than that of Rhode Island or Long Island, both of which are composed of unconsolidated glacial debris.

Postglacial Erosion in Hard Rock.

Postglacial marine erosion has accomplished almost no work upon the crystaline rock shoreline of Connecticut; nowhere along the entire shore of the State does there occur in hard rock a cliff, which owes its height mainly to wave erosion. In many places cliffs of 10, 15 or more feet in height rise abruptly from the water, but a critical examination always seems to show that their relationship to the sea is wholly fortuitous, and that the same cliffs would have been in existence whether the sea were present or not. Forbes Bluffs (Fig. 27) at Fort Hale Park on the eastern shore of New Haven Harbor are precipitous trap cliffs reaching a height of 40 feet in places. Nowhere else in Connecticut do the waters of Long Island Sound reach the Triassic trap, but here at high tide these cliffs stand in water 3 or 4 feet deep and the waves break directly upon them. At low tide a shingle beach several feet in width allows passage between the cliffs and the water, but as shown in Plate I, a and b, the cliff face is almost inaccessible when the water is high. At first sight these appear to be good examples of sea cliffs formed by wave erosion, but they can be more satisfactorily explained in another manner. The trap rock is badly fractured by confused jointing, and material removed from the cliffs by weathering usually breaks away along the joint planes in a great variety of shapes and sizes. This debris has been scattered along the shore for several hundred feet by the waves and might be taken as an indication of the disintegration of the trap under wave attack. On the other hand a visit to any of the numerous trap precipices scattered over the Triassic Lowland will show that material is constantly falling from their faces under the influence of subaerial weathering. With no agency for its removal, the broken and rough fragments of rock have collected in great slopes of talus, which now hide the bases of the cliffs from view. Subaerial weathering has been just as active on the trap of Forbes Bluffs, but there the waste material has been removed from the foot of the cliffs by the waves shortly after its fall. Thus the steep rock face of the lower part of the cliffs is kept bare and gives the impression of a ledge being actively eroded by the waves. If the submergence, which brought the sea to rest against the base of Forbes Bluffs, had been greater, and the sea instead had washed the bases of the great precipices of East or West Rock, the waves would have removed the fallen material, and these would appear as cliffs of far greater grandeur

than the Bluffs. Nevertheless as shown in Fig 16, the waves had no part in cutting any of these cliffs, which if partially submerged might be taken as an impressive example of wave work. Forbes Bluffs are trap cliffs of subaerial origin, which are thus partially submerged and give a false impression of wave cutting. Adding further strength to the view that Forbes Bluffs are not primarily of wave origin is their location well within the shelter of New Haven Harbor, where even the comparatively small waves of Long Island Sound cannot exert their full force upon the shore, while elsewhere fully exposed bare rock of no greater resistance descends beneath the water uncliffed.

If wave erosion has been an important factor in forming cliffs in hard rock along the Connecticut shore, the location of the

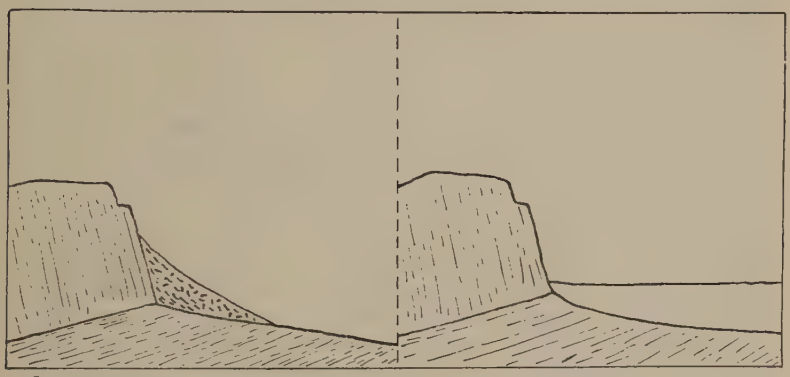


Fig. 16. Cliff with talus, and same cliff with talus removed, giving an appearance of wave cutting.

cliffs should bear some predictable relationship to their seaward exposure. In other words the most noteworthy cliffs should occur only on headlands, where the largest waves reach the shore, and should be lacking wherever wave attack is negligible. Such, however, is certainly not true of their occurrence in Connecticut, and the writer would not assign a marine origin to any of the rock cliffs that he has seen along the shoreline of the State. The land along the shore lies too low to allow the formation of any especially imposing cliffs, but those that do occur are as apt to be found facing the sheltered waters of a bay or marsh as the open water of the Sound. The sheltered position of Forbes Bluffs has already been mentioned; on the western side of Masons Island (Fig. 22) facing Mystic Harbor is a gneiss cliff 150 feet long and rising sheer to an elevation of about 40 feet. In no direction is it exposed to waves having a sweep of even one mile, and its situation is such that few would care to assign to it a ma-

rine origin. Nevertheless, if the same cliff were situated on the open Sound, it might be cited as an example of a wave-formed precipice. The highest cliff of rock other than trap along the entire shore of the State is situated in a still more protected position, for it rises steeply from a salt marsh, which, though at one time the probable site of a bay whose waters washed the base of the cliff, is now entirely lacking in open water. On the Guilford Sheet the top of this precipice is indicated by the little brown dot, which is the 100 foot contour, just south of the letter "e" in the word Sachem of Sachem Head Station. It faces the marsh to the southeast and is a continuation of the northwestern shore of Island Bay (Fig. 27), which in front of the cliff has been filled by marsh deposits. Before the filling of the upper bay the foot of the cliff may have stood in open water, but in view of its protected situation it is doubtful, if even then anyone would have been tempted to call it a wave-made cliff. It too furnishes a good example of a steep precipice which might mistakenly be assigned to a marine origin, if it were facing open water. Facing the southwest and forming the northeastern boundary of the same marsh is a granite wall, which in many places rises 10 to 15 feet in a sheer rock face. This, too, is, of course at present free from any possibility of wave erosion, but if the investigation is continued southward to the northwestern shore of Joshua Cove, a granite gneiss will be encountered in a smooth wall rising from the water 10 or 15 feet and forming the shore for several hundred feet. These two cliffs are very similar in form, yet one stands in a position, where wave origin would never be considered, while the other is sufficiently exposed to place such an origin within the bounds of possibility. In a region having the physiographic history of Connecticut all these occurrences show that a precipice fronting on open water need not necessarily be due to wave erosion. Among many similar examples one more may be taken from the southeastern shore of Joshua Cove; there the bedrock is a granite gneiss descending sharply to the water in bluffs at places 10, 15, or even 20 feet in height. Although their exposure is small, they might be interpreted as due to wave work. Nevertheless further up the hillside are found ledges of glacially smoothed gneiss which rise as steeply and as high as those at the water's edge. Clearly, if the submergence here had been slightly greater, these would have the appearance of sea cliffs possessing as great a claim to an interpretation of wave erosion as those at present sealevel. Any temptation to assign a marine origin to the higher cliffs is effectively dispelled, when it is seen that their bases do not maintain a constant elevation but change with the hillside slope indicating that they were not formed with reference to any definite horizon such as sealevel.

At times cliffs rise so steeply from the waters of the open Sound that they are almost involuntarily classed as marine in

origin. Such a one is Bluff Point shown on the New London sheet; here a greatly jointed ledge of granite rises 15 to 25 feet above sealevel. At its bases are scattered large blocks of fallen material, while others seem ready to drop from the greatly shattered cliff. On a day when a vigorous wind is driving large waves in from the southwest, the bottom of the cliff is wreathed with the white of breaking water and provides as imposing a view of rocky headland as can be found on the Connecticut coast. Seeing this, one is almost ready to accept the efficacy of wave erosion on this shore, but if Avery Point (Fig. 22) two miles further west is visited, doubt once more prevails. If anything, the latter is more exposed than Bluff Point, but although it is formed of rock of the same resistance, it descends beneath sealevel uncliffed,

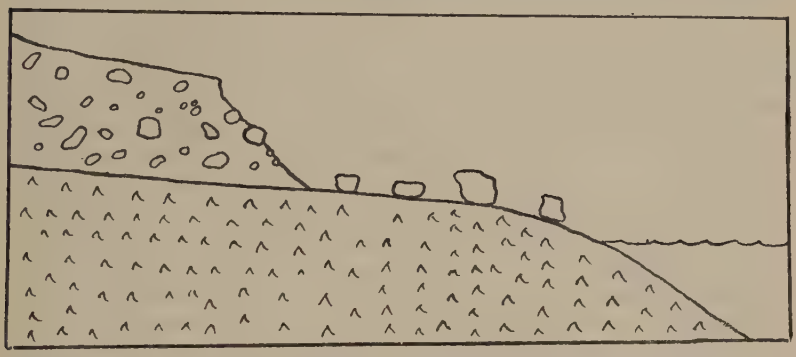


Fig. 17. Section showing relation between drift and bedrock at Avery Point.

while, as if to show the true capabilities of the waves, a 10 to 15 foot high till bank of undoubted wave origin stands at the rear of the bare and rounded bedrock platform as shown in Fig. 17. Furthermore residual boulders from the till remain on the rock surface, from which the waves have thus far been unable to remove them. Passing eastward to the Stonington sheet the comparison can be repeated as the following extract from the author's notes will show; "Wamphassuc Neck is at its tip low and composed of gneiss, which passes beneath the surface of the water without any cliffing." From Wamphassuc, Dodges Island can be seen two miles to the west partially protecting an unnamed point on which a fertilizer factory is situated at present. The exposed southeastern side of this point is composed of the same formation of gneiss as that at Wamphassuc, and in places rises in a cliff 15 feet high and 150 feet long. Yet of the two points this is somewhat less exposed, and if waves have been able to accomplish

much erosion in hard rock along this coast, Wamphassuc Neck should be the one to possess a cliffed tip.

Between New Haven and Branford a great number of rocky points and islets occur, none of which show cliffing in spite of their location opposite the widest part of the Sound.

Slight Erosion at Savin Rock.

At Savin Rock on the mainland just west of New Haven Harbor occurs a schist hill not indicated on the topographic sheet but excellently shown on Coast Survey Chart No. 218. The seaward side of this hill rises in a rough and rocky precipice reaching a height of 20 feet, and as shown in Plate II, a, the overhang is so great that incipient sea caves are formed in places. Contrary to the occurrences already mentioned, it seems to the author that the field evidence points to an appreciable though small amount of wave erosion here. The structure of the schist is favorable to erosion, and although uncliffed headlands occur in places having an equal amount of exposure, this location opposite the widest part of the Sound should be the one most apt of all the Connecticut shore to furnish examples of wave erosion. Even here little more has been accomplished than the formation of a prominent nip, which is misleading in that it seems to indicate considerable erosion. Figure 18 is a cross-section showing the structure which has resulted in the excavation of the nip. The foliation of the schist strikes nearly parallel with the shore and dips anywhere from 0 to 15 degrees away from the sea. Striking nearly parallel with the foliation but dipping from 30 to 50 degrees inland is an important system of fractures along which some movement may have occurred. One of these fractures runs along the overhanging rear wall of the nip, while another of the same system has been exposed by recent blasting a short distance up the hillside. The schist is quite closely broken by a second series of joints striking N40W and dipping 60W. Thus there are three planes of weakness causing a tendency for the rock to break away in rhombohedral blocks. The floor of the nip is a platform 10 to 15 feet broad at approximately high tide level and is quite parallel with the foliation of the rock. The nip has apparently been formed by the removal of a great wedge of rock between the joint forming its rear wall and the plane of foliation forming the floor. At the eastern end of the cliff the clearly defined wedge of rock remains in place and the nip is consequently absent. From the overhanging wall, which reaches a height of eight feet above the floor, large tabular sheets of schist occasionally fall and are removed by the waves, further enlarging the nip which is now eight feet deep. The high hill at the water's edge and the peculiar structural weaknesses of the rock at this point seems to have

combined to allow an erosion of perhaps 10 to 12 feet including the depth of the nip in postglacial time. A similar but smaller occurrence is found on a little phyllite island at Merwin Point (Plate II, b) where a cliff rises 15 feet above sealevel at low tide with a three foot nip just above ordinary high water line. Along the shore between Savin Rock (Fig. 18) and Pond Point numerous other outcrops of phyllite occur. Many are low platforms descending beneath the sea quite undisturbed by wave erosion, while others are jointed ledges a few feet high showing a few fallen joint blocks as the only evidence of wave work. The two cases of wave erosion cited are in themselves unimportant, but they

Fig. 18. Cross-section showing surface and structure of cliff at Savin Rock.

are interesting in showing how slight even this greatest amount of erosion in crystalline rock has been on this coast. (See also Fig. 28).

Uneroded Glacial Striae.

Glacial striae have been reported from all parts of Connecticut, although they are usually such shallow scratches that weathering soon obliterates them. Often those reported have been preserved under a soil cover, the removal of which has been too recent to permit the destruction of the striae. Unless weathering and erosion are too severe, the striae may be preserved in very resistant rock for many centuries. Wherever glacial striae on well exposed coasts have been unaffected by wave attack, they bear witness that marine erosion has thus far been unable to remove even

a slight thickness of the bedrock. The presence of glacially smoothed and striated rock at high tide level in a number of places on the Connecticut shore seems a safe indication of the relative weakness of wave erosion there. One or two occurrences may be mentioned; just east of Frost Point (Fig. 29) in the town of Westport occurs a low outcrop of pegmatite among the sands of the beach, fully exposed to the southeast and lying where it is washed by the waves at every high tide, it bears smooth glacial flutings, which are apparently as perfect as they were on the day of their formation. Between the Norwalk and Darien Rivers numerous large exposures of gneiss are found passing beneath the water uncliffed, and at Pine Point as at Frost Point the rock is rounded and moreover striated to the water's edge. In many other places already mentioned as showing uncliffed headlands the glacial rounding of the rock can be seen to continue beneath the surface of the water, and this is well shown in a number of occurrences in the Thimble Islands-Stony Creek region. In each case the preservation of the glacial markings lends added weight to the indications of weak wave erosion, which the uncliffed headlands, such as shown in Plate II, a, have furnished.

The Influence of Jointing on the Shoreline.

Cliffed headlands and other stretches of shore descending precipitously to the water's edge have already been described in this report as occurring on the Connecticut coast, although the author has indicated his belief that wave erosion has been an unimportant factor in their formation. Numerous observers including Shaler[1] and Willis[2] on other parts of the New England coast have likewise testified to their belief in the relative unimportance of wave erosion, while Johnson[3] after a careful analysis of the conflicting evidence and views concludes that few of the cliffs on the New England-Acadian shore show evidence of a marine origin. The Connecticut shore is as a whole so much more protected than any other section of the New England shoreline that the conclusions of these authors alone without any field examinations would point to a lack of any important marine-formed rock cliffs within the State. Nevertheless cliffs are found on the Connecticut shore, and it is necessary to explain them in some manner consistent with the physiographic history of the area, before the hypothesis of wave origin can be entirely eliminated.

Throughout the New England Upland bare rock ledges and precipices occur, which, if submerged, would form cliffs fully as striking as any of those along the present shoreline. Their origin, however, seems to be entirely non-marine, as their distribu-

[1]Shaler, N. S., "The Geology of Cape Ann, Mass.," U. S. G. S. An. Report, p. 561, 1889.
[2]Willis, Bailey, "Ames Knob, North Haven, Maine". Bull. G. S. A. XIV, p. 202. 1903.
[3]Johnson, D. W., "New England-Acadian Shoreline," pp. 159-211.

tion and form apparently indicates. Many of these cliffs occur in such protected situations that waves having a fetch of more than a few yards could scarcely have attacked them. Furthermore they occur in such large numbers at every elevation from sealevel to the highest part of New England that they cannot be readily correlated with a few stillstands of the sea but demand an almost infinite number of pauses in its withdrawal, an interpretation not readily acceptable in view of other evidence which need not be discussed here. In addition, within short distances individual cliffs in large numbers show great changes in the elevation of their bases. Deformation cannot explain this rapid rise and fall which often depends on the local topography. The inference is left that the cliffs originated in these attitudes, and hence they could not have been formed by the waves, which do their work with reference to the plane of sealevel. The identical origin of

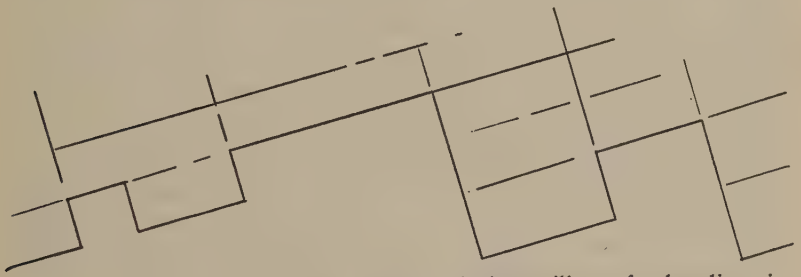


Fig. 19. Plan of en echelon offset and dovetailing of shoreline in jointed granite gneiss.

the precipices of West Rock and East Rock in New Haven and Forbes Bluffs shown in Plate I, a and b, has already been indicated. The physiographic history of all three has been practically the same, but the situation of Forbes Bluffs was such that it took the appearance of a wave-cut cliff after a slight submergence of the land brought the sea against its base. Plate III, b, illustrates a type of shoreline, which is fairly common in the Sachem Head-Stony Creek region, where a single joint plane standing more or less perpendicularly is partially submerged forming a low cliff seemingly marine in origin. The picture was taken on the northwestern shore of Joshua Cove and shows one of a series of major joints striking north 50 degrees east and forming the shoreline for a considerable distance. The shore rarely follows an individual joint for more than 200 feet before it turns at right angles along a cross fracture and then once more pursues the course of another joint parallel to the first. A jagged shoreline results sometimes with a dovetailing of land and water as shown in Fig. 19. These cliffs are believed to have originated through glacia-

tion, and the manner in which they attained an appearance suggesting wave origin may be traced in three steps by the aid of diagrams. Prior to the coming of the ice, the surface (Fig. 20, a) of the unweathered bedrock was probably extremely irregular and lay buried beneath a thick cover of residual soil and rotten rock. A powerful regime of erosion and transportation had its beginning with the arrival of the glacier. The residual soil and weathered rock was gradually removed in the bottom of the ice, and with its removal the surface of the fresh rock was exposed to the erosive action of the debris frozen solidly in the lower part of the glacier. Like a gigantic piece of sandpaper the debris-laden ice moved across the land scarring, scratching, and gouging everything with which it came in contact. This is the origin of the glacial striae and of the rounding and smoothing of the bare rock surfaces so common in Connecticut. Abrasion of this type was most important on hillsides sloping towards the north, the direction from which the glacier advanced, but the common occurrence of glacial markings on southern sloping hillsides testifies to its importance there also. The southern or lee slopes were, in addition, subjected to another kind of glacial action, which seems to have been of much less importance elsewhere. The jointing in the granite forms planes of weakness along which the rock is most easily quarried; the glacier discovered this weakness earlier than the quarrymen, and as it moved over the ledges its icy fingers fastened upon the blocks and tore them from their places. This process is known as glacial "plucking," and as shown in Fig. 20, b, it has had an important part in shaping the southern slopes of hills. Joint faces exposed by this plucking often stand in steeply sloping or vertical cliffs and walls, which after the disappearance of the ice and upon partial submergence (Fig. 20, c) greatly resemble cliffs formed by marine erosion. Unsubmerged cliffs of this type are common throughout New England, and with few exceptions the shore cliffs of Connecticut are similarly to be considered of glacial origin.

The Influence of Foliation on the Shoreline.

The Sachem Head-Thimble Islands district possesses the most intricate hard rock shoreline of any in the State and for that reason shows exceptionally well the influence of original rock structures on the coastal outline. Although not particularly apparent on the topographic maps of the United States Geological Survey, the parallelism of the alignment of the Thimble Islands and much of the adjacent mainland shoreline is very clearly depicted by Coast Survey Chart No. 217. Protractor measurements made on the chart show this parallelism to have a uniform trend of N. 50 to 60 degrees E. It is very marked and immediately seems to

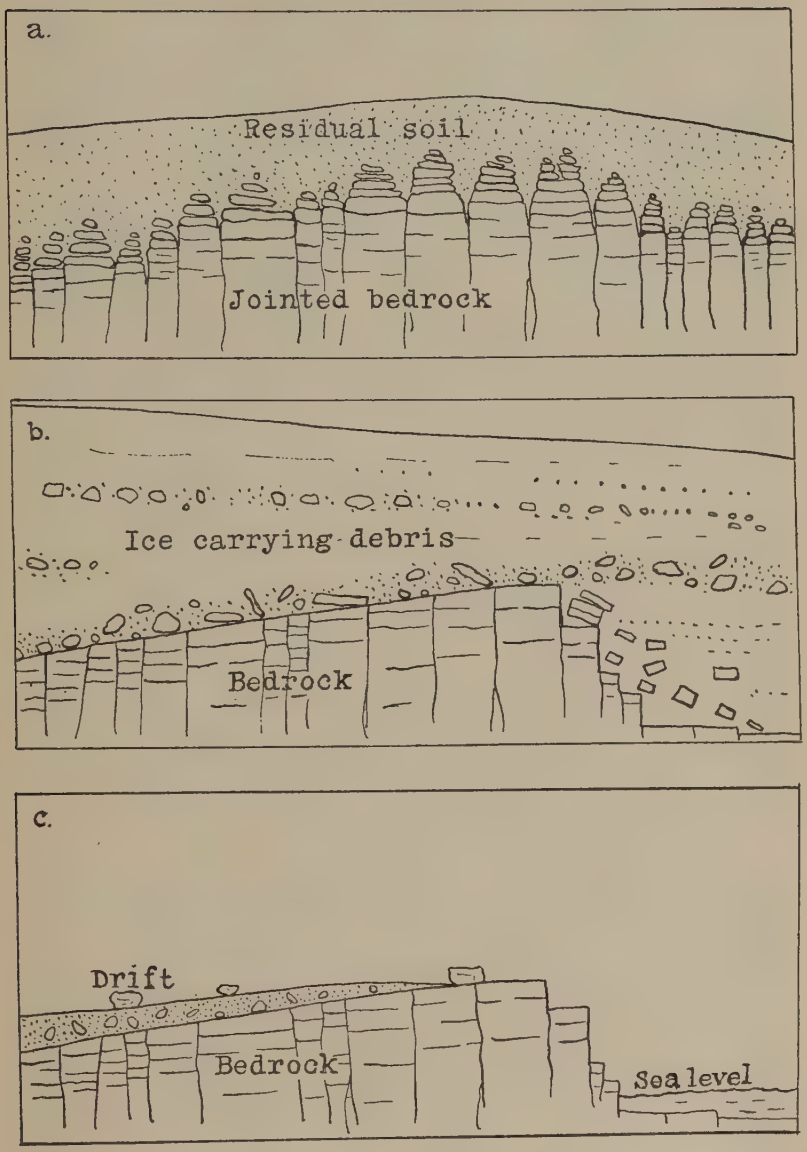


Fig. 20. a, Section showing bedrock and soil cover of preglacial hill; b, Same hill during glaciation; c, submerged to form apparent wave-cut cliff after retreat of glacier.

demand a structural origin such as faulting, folding, or jointing, or a combination of these. Major joints striking N.50 E. have already been mentioned as forming the shoreline in some localities here. The parallel orientation of much of this shoreline cannot, however, be attributed to joint control, and it is for these stretches that some other explanation must be sought. The country rock in this area is a granite gneiss, often very massive, but usually showing well developed foliation. Parallell with this foliation occur pegmatite dikes and bands of basic material, which have weathered more readily than the surrounding gneiss and form planes of weakness. The results of a number of strike measurements taken on the foliation planes of this gneiss on the Thimble Islands and on the mainland between Sachem Head and Flying Point agree with the orientation of the Islands and the shoreline to a degree, which would seem to have a genetic significance. Although with few exceptions the strike is found to vary between N.50 and 60 degrees E., it might well be doubted whether the foliation of the gneiss would have enough effect upon the topographic development to govern so closely the orientation of the surface features. As mentioned in an earlier chapter, a number of writers[1] have, however, drawn attention to the influence of the northward trend of the structure in determining the orientation of the valleys and ridges of Connecticut. Since the Connecticut shoreline in large part has been determined by the submergence of these ridges and valleys, it seems probable that its orientation may likewise be governed by structure insofar as minor features are concerned. In the field the parallelism of the foliation and the shoreline is well seen in many places, notably near Clarke and Flying Points, and on Governors, Bear, and other members of the Thimble Islands group. The correspondence is striking and hardly expectable in such a homogeneous rock as this gneiss appears to be. An extract from the author's notes will indicate that the presence of the rapidly weathering pegmatitic and basic bands is probably often of far greater importance than the ordinary foliation in directing the course of the shoreline; "Much of the northwestern shore of Island Bay is composed of granite gneiss; the orientation of the shore closely follows that of the foliation of the gneiss. Both here and in the vicinity of Hoadley Point dikes of basic minerals or of pegmatite running parallel with the foliation have weathered out more rapidly so that they have had effect in loosening the gneiss." In these cases the bands of weathered material have formed planes of weakness fully as important as the joints mentioned earlier in this chapter.

[1]Barrell, Joseph, "The Piedmont Terraces of the Northern Appalachians," Am. Jour. Sci., 4th series, Vol. XLIX, p. 248, 1920. Rice, W. N. and Gregory, H. E., "The Geology of Connecticut," Bull. 6, Geol. and Nat. Hist. Surv., pp. 75 and 76, 1906.

Features of the Thimble Islands Region.

The form and position of the Thimble Islands is determined by this foliation and by strong jointing perpendicular to it. The history of the Islands is one with the rest of shoreline area; preglacial streams following weaknesses of the rock formed ridges and valleys generally trending parallel with the foliation, when the glacier came its movement was directed by these preexisting irregularities and as a result its work too was governed by the foliation. At the same time by plucking it was removing much material along the joint planes. Thus, when finally the region was submerged, the tops of the former ridges made islands elongated in the direction of foliation and terminated by irregular cliffs where the jointed rock had been quarried by the ice.

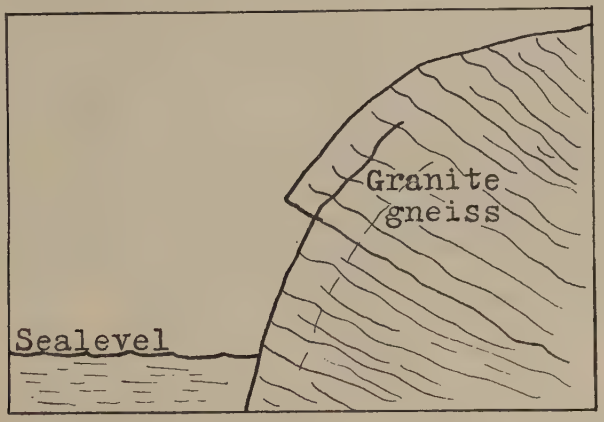


Fig. 21. Concentric jointing forming shore at Joshua Cove.

In Joshua Cove and the marsh behind it occur several islands formed of aplite, a rock here consisting largely of quartz, to whose resistant qualities they owe their existence. The connection between these outcrops cannot be traced on the surface, but lines can be drawn between them parallel with the foliation of the surrounding gneiss, and they probably indicate irregular dike-like masses. If so, they may represent the unsubmerged parts of former quartz ridges and add further strength to the evidence showing the influence upon the detailed shoreforms of differences in rock resistance of the various structural planes. In any case the islands themselves probably owe their existence to the superior resistance of the quartz.

Among the many interesting small details of this region one remains to be briefly mentioned. In many of the nearby commercial stone quarries the concentric jointing is very remarkable,

and in a few cases there is evidence that this type of jointing has formed the shore. Such may be true of the southeastern shore of Joshua Cove, where a section (Fig. 21) near the top of the steepest slope indicates that a slab of gneiss has been torn off in the same manner that one of the concentric layers of an onion might be removed. Thus the water comes to rest against the rounded and perhaps glacially modified surface of the more recently exposed joint plane, the direction of which becomes that of the shoreline for a short distance. Some of the Thimble Islands may also show the result of similar concentric jointing.

Summary.

Consideration of the evidence to be seen at the shore today leads to the conclusion that the sea has been unable to accomplish more than a modicum of erosion on the hard rock parts of the Connecticut shoreline in postglacial time. This means that it is still well to build "your house upon a rock," although the bathing in the vicinity is much less apt to be satisfactory due to the comparative rarity of good beaches on rocky coasts. Those cliffs, which do occur at the shore, are interpreted not as the result of wave attack but as due to the partial submergence of precipices caused by glacial erosion. In addition various examples showing the effect of rock structure in governing the form of the minor irregularities of a shoreline of submergence are cited.

CHAPTER VI.

POSTGLACIAL CHANGES AND THE PRESENT SHORELINE: SHORELINE FORMED OF UNCONSOLIDATED DEPOSITS.

The sum total of all the postglacial changes of the hard rock shoreline of Connecticut are small, but when the attention is directed toward the modifications which have taken place in the unconsolidated deposits of glacial and other origins, they are seen to be of infinite number and detail. Not only is this true, but the changes still occur so frequently that as stated by an engineer familiar with shore protection work, "A complete and very detailed map of this shore might be made, and in two years it would be largely out of date." The causes of these changes have been briefly discussed in Chapter II of this bulletin, and in the following pages they will be only incidentally mentioned in connection with the forms they produce. No attempt will be made to treat all the erosional and depositional forms which are found on the Connecticut coast, for after one of a type has been described further description of similar features leads to needless repetition.

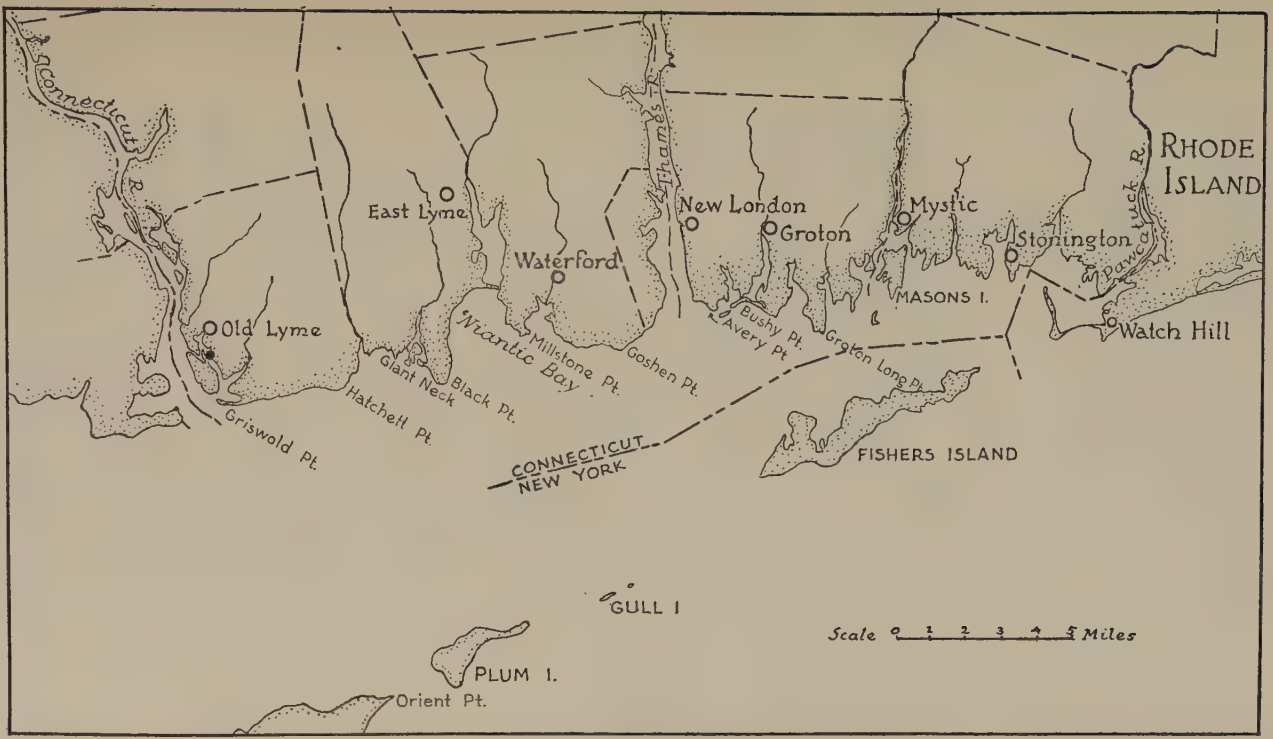


Fig. 22. Outline map of the shore between the Pawcatuck and Connecticut Rivers.

Where several excellent examples of the same feature have been developed, however, all will be briefly described or cited in an effort to make the bulletin more useful to those visitors or residents of the shore who may be interested in the origin and changes of its present outline. For convenience of treatment the shoreline will be divided into districts, and the marine depositional and erosional forms of each district will be discussed separately from those of other districts.

District between Pawcatuck and Thames Rivers.

The easternmost of these districts is that lying between the mouths of the Pawcatuck and Thames Rivers and shown in Fig. 22. It apparently is not especially prone to further marked changes in shoreline. The entire shoreline is greatly protected by the close proximity of Fishers Island, three miles to the south, too near to allow the generation of large waves. The waves seem to have accomplished long ago all the work of which they were easily capable, when they either removed the covering of glacial drift from the crystalline rocks, or gnawed so far into the morainal deposits that the boulders which they could not remove serve as a protecting bulwark against their further advance. At Avery Point (Fig. 17) may be seen an example of the former case, while Pawcatuck Point, composed of morainal material, now faces the waves in a wall of glacial boulders ranging in size up to that of a large automobile. Whatever soil was mixed with these has long since been removed, while they, too large to be removed and too resistant to be rapidly eroded, stand as a protection against further erosion. Although Groton Long Point is also protected in this manner, the size of the boulders is smaller, and they are not closely enough grouped to entirely prevent erosion. Many of these points, which are composed of moraine, show by the presence of a broad fringe of offshore boulders that they have suffered extensive erosion in the past; the boulders are the only part of the moraine with which the waves have been unable to make way. Stonington Point, an example of such, possesses a fringe of boulders at least one hundred feet wide, although the presence of a strong seawall and a breakwater, built in 1895, seems to show that erosion must have been slight for the past few decades.

Tombolos of the Groton Long Point vicinity.

Due to the protection of Fishers Island and the resistance opposed to erosion by the materials composing the shore, this district possesses one of the most irregular and least modified shorelines of any in the State. Nevertheless, in addition to the slight work of erosion just mentioned, the waves have also tended to

simplify the shoreline somewhat by a few depositional features of interest and importance. Chief among these is the succession of two tombolos, the younger of which forms Groton Long Point Beach extending westward from the western side of Groton Long Point and shown in Fig. 23. Back of Long Point Beach and separated from it by a lagoon, extends westward another bar, similar in length, but narrower and older than the Beach. Groton Long Point Beach ties a low boulder island to the mainland and is technically known as a tiebar or tombolo. In the field the curve

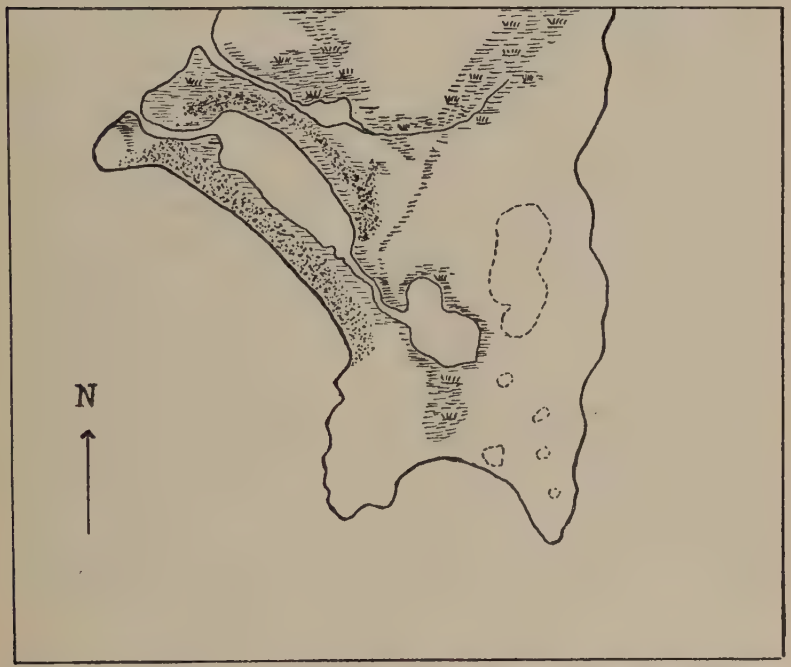


Fig. 23. Tombolos of Groton Long Point Beach (From Coast Survey Chart, No. 358)

of the older bar suggests very strongly that before the formation of the younger Groton Long Point Beach, it was tombolo tying the island to the mainland. If so, slight modifications in the neighboring shoreline were apparently sufficient to cause the path of shore drifting to shift a few hundred feet southward, abandoning its course along the front of the old tombolo to follow a new one coincident with Groton Long Point Beach. The marsh, which fringes the lagoon and lies behind the older tombolo, could not have developed until the formation of the bars afforded it protection, although its presence tends to obscure the origin of the

bars as true open water forms. Some time during or after the formation of the younger tombolo the older was breached near its attachment to the island, and the inlet, which at present permits entrance of seawater to the lagoon, was formed. The older tombolo is noticeably narrower and lower than the younger, and it is possible that for an unknown time before the latter grew above sealevel the supply of sand was delivered entirely to it, and the older tombolo cut off from its source of building material suffered considerable diminishment under the attack of waves still able to get over the bar. Groton Long Point tombolo is now about three hundred feet broad and is covered by low sand dunes fixed by vegetation.

With proper caution a succession of beaches, such as just described, may be used as evidence of changes in the relative level of land and sea. The crest of the older tombolo at Groton Long Point is notably lower than that of the younger, and must indicate submergence since its formation, if it is assumed that the older at one time was equal in height to the younger and has suffered no lowering due to erosion. In the same way, if the older were now higher it might indicate emergence. Johnson[1] has discussed in some detail the use of beach ridges as evidences of changes in level, and the subject will be mentioned here only in connection with the tombolos of Groton Long Point. Does the lower elevation of the older tombolo indicate submergence? Even if the Connecticut coast should prove to have suffered slight submergence in the time since the formation of the older tombolo, it seems to the author distinctly unsafe to assign more than a modicum of the difference in elevation between the crests of the two ridges to this cause. Other causes are more than competent to explain the difference. Since the first tombolo is located somewhat nearer shore and further up a slight embankment than the second, it is likely that the waves building it were smaller and never able to raise it to the height above sealevel that the larger waves have carried the second and more exposed tombolo forming the present beach. Furthermore the growth of the older tombolo ceased when the younger interrupted its supply of sand, and since then the wind, the rain, and the little waves of the lagoon have united to decrease its size by the gradual removal of material never to be replaced. These agents are probably by far the most important cause of the difference in elevation.

From Bluff Point, the headland immediately west of Groton Long Point, a mile-long tombolo stretches in a beautiful crescent beach to a former island, now Bushy Point. On Chart No. 358 Bluff Point is called Mumford Point, but the usage of the United States Geological Survey and the local inhabitants sanctions the name, Bluff Point. This tombolo is free from vegetation and the

[1]Johnson, D. W., "Shore Processes and Shoreline Development", pp. 439-452.

debris lines indicate that waves wash over it during heavy storms. It is composed of sand and pebbles, probably receiving its supply from the wasting of Bluff Point, and Bushy Point, the latter being composed of moraine. A good sized marsh is growing within the protection afforded by it, but as yet marsh material has not gained enough foothold on the rear of the bar to obscure its origin as an open water form. The curve of Bushy Point Tombolo is very similar to that of that of the two Groton Long Point Tombolos as is its position in reference to its headland; these may be coincidences of no significance, but it is more probable that they indicate the greater influence of waves coming from the southwest, the quarter which is not protected by Fishers Island.

Between Avery and Eastern Points just east of the mouth of the Thames is situated Shennecossett Beach, very popular during the bathing season. It is a dune-covered bar, separating from the Sound, a small pond, the water of which judging from the character of the vegetation, is fresh. The basin occupied by this pond is undoubtedly a part of the Sound which was cut off by the growth of the bar. In the past the bar may have been further south and the lagoon correspondingly larger. Continued retreat of the bar in accordance with the usual history of such forms is expectable, and it will gradually but inevitably encroach upon the lagoon, restricting its area, and finally, when the bar reaches the inland shore, destroying it. At the time of its origin the pond behind Shennecossett beach contained salt water and was probably in direct contact with the ocean by means of an inlet through which the tides flowed. With the advance of the bar the inlet became closed, and the inflow of fresh water diluted the salt and made a fresh pond from which water may flow by seepage through the bar. On the Rhode Island coast many ponds of similar origin may be seen, and they are not uncommon features along the shore of the eastern United States.

CLAM POINT CUSPATE BAR.

Last of the depositional features of this district to be mentioned is a small but very perfect example of a cuspate bar forming Clam Point on Masons Island near the village of Mystic. Just large enough to be indicated on Coast Survey Chart No. 358, it is represented in greater detail in Fig. 24. Both limbs of the bar are apparently retreating at the present time, judging from the presence of recently exposed marsh peat in front of them and from little pebble deltas so recently deposited within the triangle that a scanty growth of marsh vegetation has just begun to straggle through them. The origin of cuspate bars[1] is often determinable with difficulty, but there is one bit of evidence pointing to the origin of Clam Point by shore drifting in opposite di-

[1]Johnson, D. W., "Shore Processes and Shoreline Development," p. 318.

rections. This is the presence of Sixpenny Island directly across the bay from the end of the Point in such a position that it prevents large waves from the north from readily getting south of it and large waves from the south from getting north of it. Consequently under the influence of the stronger waves shore drifting south of Clam Point is mainly northward, north of it mainly southward. The two arms of the cuspate bar are thus formed by shore drifting from north and south. After a heavy storm it may be found that a projection has been built on the apex of Clam Point extending in the direction in which the heaviest waves are

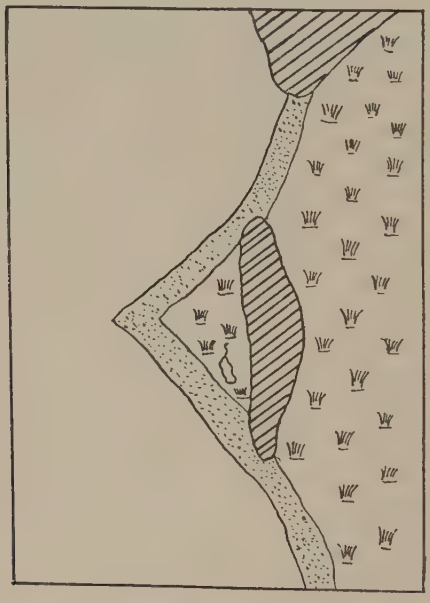


Fig. 24. Diagram of cuspate bar at Clam Point, Mystic Harbor.

running. The end of the bar, however, is located at the point of equilibrum between the force of the waves coming from the two directions, and any unequal growth resulting from a preponderance of movement in one direction during a storm will usually be rapidly eradicated in calm weather or during a storm from the opposite direction. As a rule therefore the cuspate form of the bar will be unmodified. Though small it is one of the best exhibitions of this shore feature to be seen on the Connecticut coast.

Shoreline between the Thames and Connecticut Rivers.

The next district arbitrarily chosen for convenience of discussion is that comprising the shoreline between the mouths of the

Thames and Connecticut Rivers and shown in Fig. 22. The lower courses of both of these streams are excellent examples of drowned valleys or estuaries caused by the submergence of a former land area with resultant flooding of the lower parts of the stream valleys. Connecticut has been lowered so much in relation to sea-level that the valley of the Thames is entered by the tides as far as Norwich, while in times of low water the tides are perceptible as far as Hartford on the Connecticut River. Thus the lower part of neither of these rivers is rightfully to be considered as a stream but as an arm of the sea.

CONTRAPOSED SHORELINE.

In contrast to the shoreline of the district immediately to the east, the shore between the mouths of these two estuaries is notably more even. Rock and boulder headlands are not lacking, but they are present in smaller numbers and form less prominent features, while between them sweep the long, gently-curved crescent beaches characteristic of a shore composed of alternate stretches of resistant and non-resistant materials. Much of the shoreline is formed of easily eroded moraine or fluvioglacial deposits, and the simplicity of its outline is that of approaching submaturity. At the time of its submergence it undoubtedly possessed an outline, the irregularity of which approached that of the present hard rock shorelines of the State; but the glacial debris has been so much more easily eroded that shores composed of it are reduced to simple lines, while those in hard rock are practically untouched. Thus the many indentations containing gently curved beaches have been excavated in unconsolidated material, while the headlands and points, composed of rock or of great boulders, stand out because the waves cannot erode them backward so rapidly. Many of the bedrock prominences of this and other parts of the Connecticut shorelines are small but good examples of what Clapp[1] has called contraposed shorelines because of their analogy with superposed rivers. A contraposed shoreline may be simply defined as one in which the waves, originally working on a comparatively easily eroded rock, have through their own excavations exposed an underlying more resistant rock upon which they are now forced to work. Thus in Connecticut many of these hard rock points were at one time entirely covered by glacial deposits; but marine erosion rapidly removed this non-resistant material, and the waves must now attack the resistant rock against which they have become placed through their own efforts. In the future as more of the glacial deposits are stripped away, it is evident that a much larger proportion of this shoreline will be contraposed. When contraposition is complete, all the hidden in-

[1]Clapp, C. H., "Contraposed Shorelines," Jour. of Geol., Vol. XXI, pp. 537-540, 1913.

equalities of the crystalline rock surface will have been exposed by the removal of the overlying cover, and the shoreline, which may have had the straightness of sub-maturity in the soft rock, will again take on the irregularity of youth. Until then the projection of the contraposed hard rock beyond the unconsolidated deposit stretches of the shore is another indication of the great difference in resistance to wave attack of crystalline rock and glacial debris.

ROCK HEADLANDS.

Curiously enough the few large crystalline headlands of this district tend to be situated within protected bays or reentrants of the coast, while the most exposed parts of the shore are composed of glacial deposits, with an occasional projection where an inconspicuous outcrop of the crystallines has been uncovered by erosion. Thus McCook Point, Giant Neck, Rock Neck, and Millstone Point, all composed of hard rock, are comparatively protected, while Goshen Point, Black Point, and Hatchett Point, composed of glacial debris, are prominent features more fully exposed to wave attack. In time this relationship will be reversed, and the most prominent points will be composed of bedrock, while the shore will be composed of glacial materials only within the protected bays. The present situation is probably due to the irregular deposition of glacial material upon the crystalline basement; where a thick mantle of glacial deposits covers the bedrock, it is evident that the shoreline must be further seaward than where this mantle is lacking and the sea comes directly to rest against the crystallines.

The most prominent headland of glacial till is Black Point, an oblong hill, with its longer axis extending seaward. It superficially resembles a drumlin, but lacks the evenly rounded contours of that form; the presence of bedrock at several places along its shore indicates the probability that it contains a core of solid rock. The simple shoreline of Black Point is due to its exposed location and its glacial till composition, which have allowed the waves to remove quickly any initial irregularities. As a rule the beaches are of poor quality, being composed of glacial boulders of all sizes left behind by the waves, which have removed the fine material. Behind the beaches the till often stands in fresh and overhanging banks ten feet or more in height, indicating that erosion is continuous and recent. A tombolo extending westward from the western side of the Point unites a former rock island to the mainland and forms a good bathing beach; it shows what becomes of much of the fine material carried away from the wasting tip of the Point.

GOSHEN POINT.

Goshen Point is the culminating point of a broad blunt headland lying between Jordan Brook and the Thames River. The slight projection of the Point is due to large boulders of till, which have held up erosion while the shore on either side composed of stratified drift has retreated more rapidly. Most of the upland is composed of stratified sand and gravel apparently deposited as an outwash plain, and its erosion has furnished an abundant supply of fine material resulting in the formation of many excellent beaches. Without regard to exposure these beaches showed a seaward slope between high and low tide lines of six to eight degrees. In many places overhanging banks in the drift indicate rapid erosion and the general absence of the protection afforded by large boulders lays outwash plain shorelines open to more rapid retreat than shorelines formed by any other type of glacial or fluvioglacial deposits.

SHORELINE CHANGES IN OLD LYME.

The upland from Hatchett Point west to the Connecticut River is composed almost exclusively of stratified sands and gravels forming a low plain. At present its greatest width between the Sound and the southernmost crystalline hills is a scant half mile, although evidence pointing to a width one quarter to one half mile greater is not lacking. As shown in Fig 25, the plain is crossed by a number of southward flowing streams, the lower valleys of which contain marshes shaped roughly like isosceles triangles with the base at and parallel with the shore. These triangular marshes have been formed by the drowning of a number of shallow broadly flaring valleys in the plain. The shape of the upland area between these valleys is significant in the restoration of the shoreline. They are seen to taper naturally in the opposite direction to the valleys, that is, toward the shore, but instead of continuing to a point, they are truncated sharply by the shoreline. This is undoubtedly due to erosion, and a reasonable restoration of the original shoreline can be made by continuing the taper outward (Fig. 25). By a somewhat similar method Davis[1] made his restoration of the outer arm of Cape Cod, and the dotted line in Fig. 25 attempts to locate approximately the former shoreline of the lobes of the Old Lyme plain west of Hatchett Point.

Most of this area continues to be rapidly eroded, and the break between the surface of the plain and the beach is usually a cliff from two to ten feet in height. In many places fallen blocks of sod with the grass still growing testify to the recency of the destruction, which according to Mr. A. S. Howard of Black Hall, has driven the shore 50 feet northward within a generation. The

[1]Davis, W. M., "The Outline of Cape Cod," Am. Acad. Arts and Sci., Proc. XXXI, pp. 303-332, 1896.

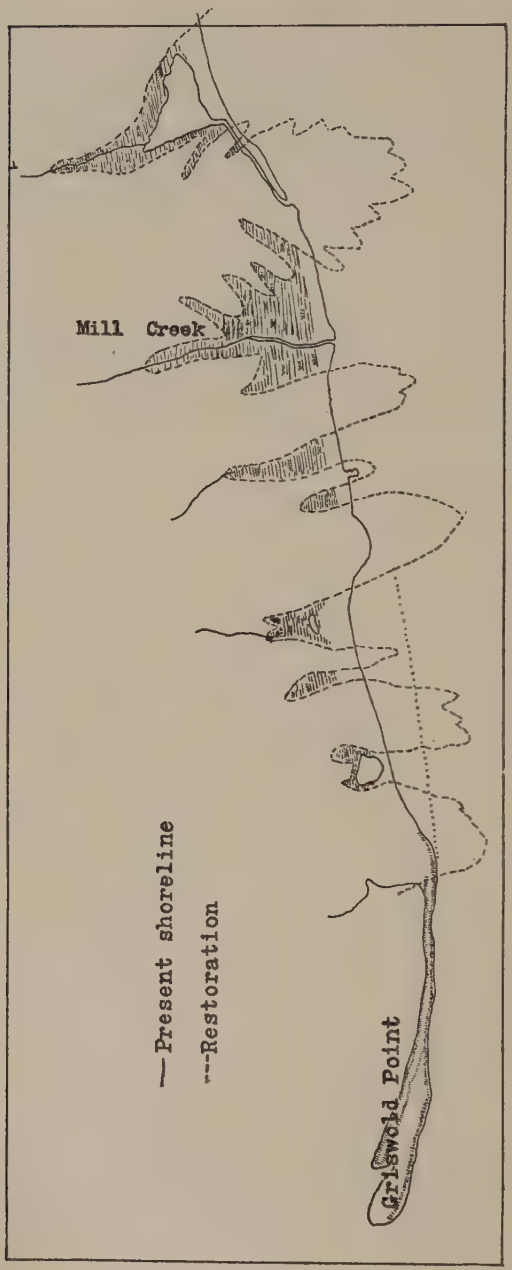


Fig. 25. Restoration of shore plain at Old Lyme.

impressiveness of a cliff increases with its height, and so usually does the observer's estimate of the importance of wave erosion. Nevertheless it is apparent that a high cliff need indicate no greater annual retreat of the shore than a low embankment. In fact, a high cliff once established is likely to retreat more slowly than a low one, for with every foot of its retreat the sea must do much more work than for an equal retreat of a low cliff. In the ideal case of two vertical cliffs, one ten foot high, and the other one foot high, it is evident that for every foot of retreat of the ten foot cliff the sea must assimilate ten times as much debris as in a like retreat of the lower cliff. It has to accomplish ten times as much work, and if its energy is equal in both cases, it will take in the order of ten times as long. Shoreliness of outwash and other stratified material are ordinarily very low, and in accordance with the above their retreat is apt to be very rapid unless retarded by special conditions such as location behind a barrier beach as is illustrated in southern Long Island. This together with the small size of their component sand and gravel particles makes them the most unstable of the shorelines formed by glacial deposits.

In a few places the stratified deposits give way to bouldery till, and without exception the superior resistance of this material makes a projection in the otherwise even shoreline. Hatchett Point is thus formed and is fringed at the tip by a ring of boulders, while the hill something over 40 feet high situated about half a mile west of Mill Creek is likewise responsible for an inconspicuous boulder fringed headland. The latter hill has the shape of and probably is a drumlin. Although more resistant than the outwash, erosion along its southwestern exposure has been so great that the road much used by summer residents is in serious danger of being destroyed.

Except for a few stretches of bedrock the entire shorefront from Hatchett to Griswold Points is composed of low beaches of fine sand offering excellent bathing facilities. Many of these are in the form of bars extending across the mouths of the interlobate streams, which through drowning have usually expanded into small salt marshes or ponds. The summer cottages in many cases are placed directly on these bars, which in time of storm are often flooded, making a most precarious foundation. Rude efforts at shore protection have been made in a number of places, but most of these have proven ineffectual, and it has been necessary to move a number of cottages backward with the retreating shore. Much of this shoreline was until recently undeveloped, and the value of the land lost through erosion was not great enough to justify the cost of protective structures. In the future, however, the increase in value coincident with its development for shore resorts will make economically feasible reasonably expensive works for its preservation.

THE GRISWOLD POINT COMPOUND SPIT.

Griswold Point, a sand spit, formed entirely by the deposition of material carried by the waves, extends seven tenths of a mile outward into the Connecticut River and is the second largest feature of this kind found on the shore of the State. At its connection with the mainland it is only 200 feet in width, but it broadens rapidly westward, where a very perceptible ridge lying behind the present front of the spit marks the old position of its shorefront. The curve of the inner ridge shows that at the time of its formation the shore of the mainland lay considerably further south. A restoration (Fig. 25) of the shoreline based on the curve of this old beach ridge indicates that since its formation a maximum retreat of about one quarter of a mile may have oc-

Fig. 26. Wave intercision west of Hatchett Point.

curred. Although this lies within the limits of the former shoreline as indicated by the restoration of the adjacent plain, no great accuracy can be claimed for the estimate. To allow the accumulation of such a ridge the shorefront of the spit must have remained in this position for a long time, before it gradually moved forward and occupied the present position, which judging from the same criteria, it must also have occupied for some time. The distal ends of these two ridges give the spit two hooks, and to this type of shore feature the term, compound spit, has been applied. It represents a definite succession of events in the erosional and depositional history of a shoreline. The broad distal area and the comparatively narrow bar connecting with the shore are features common to all compound spits due to their method of origin and are well illustrated in Sandy Hook and in Presque Isle[1] on Lake

[1]Johnson, D. W., "Shore Processes and Shoreline Development," pp. 287-300.

Erie. This difference in dimensions is caused by a change in the direction of the shore currents, which gradually build the beach forward and outward near the end of the spit at the same time that the part nearer land is being pushed backward. Thus the outer part may continue to gain in area while the rest remains the same or actually becomes somewhat smaller.

SMALL CASE OF WAVE INTERCISION.

A feature of no importance to the physical history of the shoreline but of interest to physiographers as an illustration of a specialized type of drainage modification may be seen on the lower course of the first stream entering the Sound west of Hatchett Point, Coast Survey Chart No. 215 and the Saybrook Sheet of the United States Geological Survey show this stream to bend sharply to the east just before it reaches the Sound, which it enters immediately west of an outcrop of bedrock. The deflection of the stream course was apparently due to a bank of sand dunes reaching a height of ten feet and barring the most direct course to the sea. When the writer visited the locality, however, vigorous wave attack had breached the dunes about 200 feet west of the mouth of the stream, and the channel below the breach had been abandoned for the more direct route to the sea through the break. The entire course of the old channel could be plainly traced (Fig. 26) furnishing an example of what has been called "wave intercision"[1], a process not entirely rare on coasts undergoing rapid erosion.

Shoreline Between Connecticut River and East River, Guilford.

The third district into which the shoreline has been divided is that comprised between the mouths of the Connecticut River and East River, Guilford, and is shown in Fig. 27. It forms the shores of the towns of Old Saybrook, Westbrook, Clinton, Madison and part of Guilford, comprising some of the most popular and fashionable beach resorts of the State. Its physical features do not essentially differ from those of the shoreline district immediately to the east, which has just been described in the preceding pages. It does not, however, possess even one crystalline headland as large as Giant Neck or Millstone Point, and its features are, therefore, even more predominately those of a shoreline bordering unconsolidated deposits than are those of the preceding distict. Hammonasset Point, Kelsey Point, Clinton, and Cornfield

[1]Goldthwait, J. W., "Intercision, a Peculiar Kind of Modification of Drainage," Sch. Sci. and Math., Vol. 81, pp. 129-139, 1908.
Arber, E. A., "The Coast Scenery of North Devon," pp. 1-261, J. M. Dent, London, 1911. pp. 230-239.

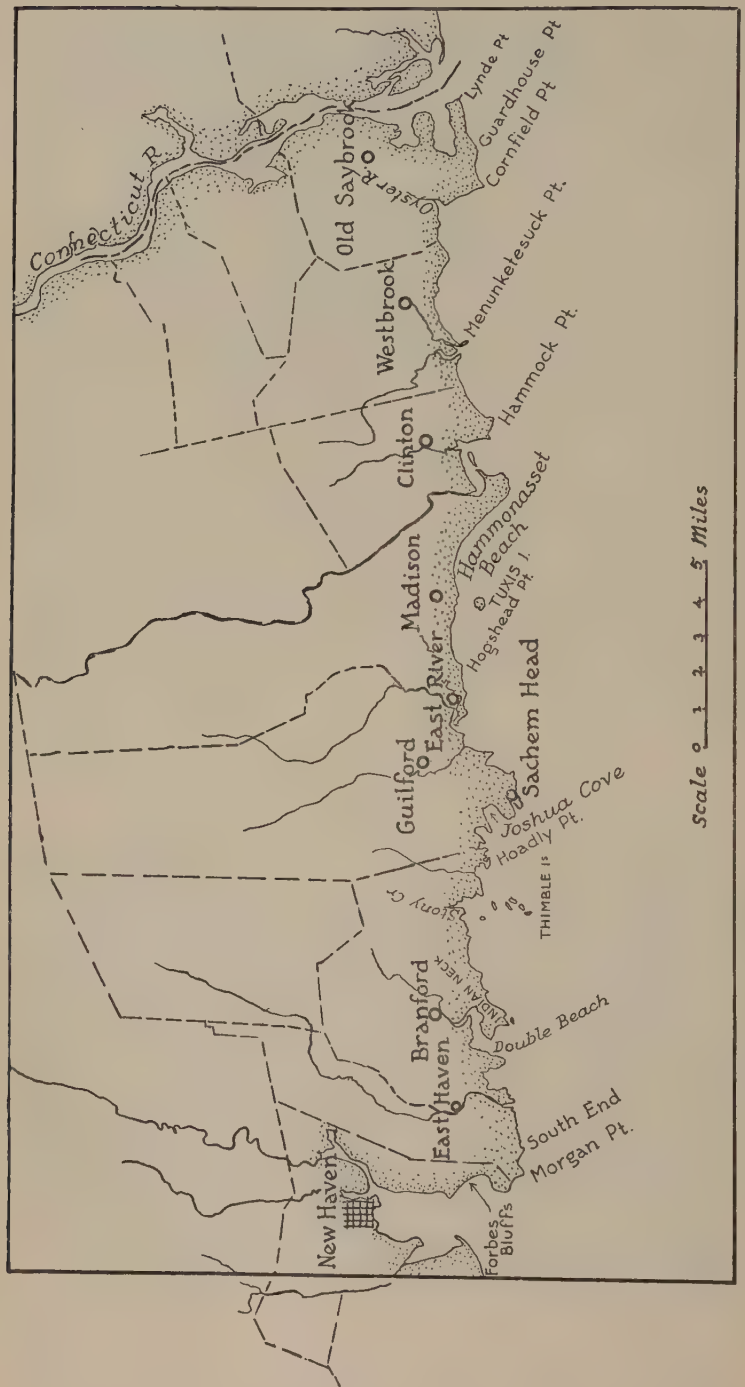


Fig. 27. Outline map of the shoreline between the Connecticut River and New Haven Harbor.

Point, the three largest projections, are composed of glacial till, while Old Kelsey Point, erroneously called Chapman Point on the Saybrook Sheet, is a relatively inconspicuous projection formed of bedrock. Only a few other outcrops of bedrock occur on the shoreline, and none form prominences worthy of special note.

Much of the upland is composed of stratified sand and gravel, and as is usually the case the erosion of this material has resulted in the formation of many excellent bathing beaches. These swing from point to point in long crescents, and no better example of crescent-shaped beaches can be cited than those lying between Old Kelsey Point and Menunketesuck Point, or Menunketesuck Point and Kelsey Point. The entire shoreline of this district is a succession of such intersecting arcs of circles, as if a giant biscuit cutter had removed biscuits from the upland. The shoreline is fairly regular, but if all the depositional features and the salt marsh deposits were to be removed, and if their places were to be occupied by the waters of the Sound, it would be evident that its present regularity is not that of maturity. A mature shoreline of submergence may be defined as one in which erosion has driven the shore back to the heads of the drowned valleys and removed all the irregularities. It is plain that the shoreline of this district has not yet reached this stage of its evolution. Many inequalities have been concealed by deposition, but they must be destroyed by erosion before the shoreline become mature. Study of the maps covering this area shows that erosion is responsible for much less of the straightening of the shore than deposition, and it is clear that the entire shore must suffer an average retreat a mile or more before it can be called mature. At present its development is not yet beyond the stage of late youth.

Since many of the shore forms of this district are repetitions of those found in the districts previously discussed, it will only be necessary here to call attention to those the size or physiographic significance of which is especially noteworthy.

CORNFIELD POINT TO LYNDE POINT LIGHT.

The stretch of shore from Cornfield Point to Lynde Point light is greatly exposed and consequently shows many evidences of erosional and depositional changes. No outcrops of bedrock occur, but the tip of Cornfield Point and the shore for a short distance eastward is fronted by immense boulders, which oppose a fairly effective barrier to further erosion. For most of the distance from Cornfield to Guardhouse Points this protection is lacking however, and overhanging, bare cliffs of till ranging from 20 to 40 feet in height and stituated dangerously near the main highway draw attention to the great need of protection. From Cornfield Point

west to the beginning of the Oyster River marshes the upland similarly ends in an overhanging and eroding cliff, and here a local resident pointing out to sea said to the author, "There used to be a hitching post there, which we could walk around." The same observer had noticed that ice and logs carried down by the spring freshets of the Connecticut River furnished an especially efficient battering ram to the waves in their attack upon the shore at this locality. Along the shore west of Cornfield Point the movement of debris is dominately westward and northward, and a low ridge of sand, probably derived from this material, has been thrown upon the seaward edge of the Oyster River marshes by the waves. East of the Point drifting as indicated by the accumulation of sand on the western side of groins is predominately eastward, and beyond Fenwick the shore is largely composed of material transported from the till headlands by the waves.

At Guardhouse Point a heavy concrete seawall with numerous groins has been erected; this should protect the road, which runs very close to the shore, from further danger of destruction. Most of the shore at Fenwick is defended by a well-constructed concrete seawall opposing a concave face to the waves. Walls of this form are built to throw the swash of the breaking waves outward. They seem to be generally successful in fulfilling their purpose and are recommended for use wherever the impact of waves striking a vertical wall is likely to throw a heavy column of water high in the air. If such a column shoots vertically upward, it is likely to fall on the upland behind the wall, eroding it and eventually leaving the wall open to destruction through lack of support or undermining from the rear. Timber seawalls were also observed at Fenwick, and in contrast to concrete they seemed to be subject to one defect, which in places seriously impaired their value. Where the joints between the timbers were not absolutely tight, it was evident that water had seeped back and forth through the wall. This seepage would be unimportant, did it not generally carry considerable amounts of fine material out through the cracks finally resulting in the caving of the upland immediately to the rear of the wall. Not only does this result in unsightly lawns, but the removal of support from its rear means a serious weakening of the wall.

The construction of the Saybrook jetties has resulted in considerable prograding of the shore immediately adjacent to the point where the western one joins the mainland. According to the keeper of the Saybrook Light the shore immediately east of the jetty has added 20 feet in the last two years, while another observer states that the shore is adding 10 feet a year just west of it, and has grown 150 feet seaward within his memory. A broad, weed-covered sand flat standing well above high tide level curves outward two or three hundred feet along the side of the

jetty, and in conjunction with the underwater contours, which show an even more marked outward swing, seems to indicate an advance of the shoreline of about this amount since the building of the protection. The material for this accretion has been gained from the erosion of the shore to the west, and the protection afforded by the jetty has undoubtedly facilitated the eastward movement of material by preventing the attack of large waves from the east to a distance at least as far west as Guardhouse Point. At the same time the jetty acts as a great groin catching and temporarily holding all the eastward-drifting material and thus causing the locally great advance of the shore.

Between Lynde Point and Fenwick the rest of the shore is formed by a low sand and cobble bar extending along the front of a marsh. This bar is breached in several places, and material from it has been spread over the marsh in thick, steep-fronted, delta-like lobes. Breaks of this type usually occur during severe storms, when at high tide the waves beating over a low place in the bar quickly erode a channel, which is rapidly widened and deepened by the current of water flowing from the higher level of the ocean to the lower level behind the bar. The material from the break is deposited as soon as the quiet water temporarily inundating the surface of the marsh a short distance away is reached. Under the attack of storm waves not only are bars broken in the manner described, but they are pushed bodily backward over the marsh, so that broad expanses of marsh peat may be seen in front of them, although it could not have grown in such an exposed locality. Parts of the bar here under discussion are said by the lighthouse keeper to have been pushed backward a hundred feet during single storms, and it is clear that when summer cottages are built on similar bars the owners are courting disaster. Not without cause does the costliness of shorefront homes usually increase with the stability of their foundations.

STORM DAMAGE WEST OF OYSTER RIVER.

On Saybrook Manor Beach, a short distance west of Oyster River, is found one of the most interesting examples of recent retreat of the shoreline to be seen on the Connecticut coast. According to information furnished by the owner, the front of the house shown in Plate IV, was situated about 30 feet behind the high water line a quarter of a century ago. Today the shore has retreated about 100 feet from its former position leaving the house standing on piles at a considerable distance seaward of the high tide line. Just beyond several broken piles projecting above water indicate the former position of another house, whose destruction in a storm several years ago furnished debris with which the waves severally battered a number of buildings situated within

their reach. Since submerged lands bordering the sea generally belong to the State, the present ownership of the house constitutes an interesting legal problem.

The marsh lying behind the bar between Oyster River and Old Kelsey Point was being filled by pumping sand from the ocean bottom in 1927, and many residents were concerned over the possible ill effects upon their beaches of disturbing the adjacent ocean floor. Theoretically every bit of sand which is removed will result in a steeper underwater profile, which in turn will allow large waves to approach nearer shore than before. Under such circumstances the shore might be eroded more rapidly than before the disturbing of equilibrium, but no cases have been reported where the removal of sand from the bottom at a point several hundred or more feet from a beach has had a noticeably bad effect. The removal of sand or shingle from the beach itself is another thing, and in the British Isles and various countries of the Continent, it is unlawful to remove material from the beach for any purpose, since it is recognized that the greatest protection a shore can have is an abundant supply of sand. The bar in front of the marshes mentioned above has been broken many times during heavy storms, and wide areas of the marshes and adjacent low-lying upland have been flooded. Erosion along this shorefront has been severe, and some old residents assert that the shore used to be located a couple of hundred feet further south.

MENUNKETESUCK POINT.

The shore at Westbrook is cut in a lowlying plain, the sands and gravels of which have furnished an abundance of material for excellent beaches. A tombolo 400 feet wide in places, on which are developed the best sand dunes of the Connecticut coast, extends westward from the mainland toward Menunketesuck Point, an island which it ties to the land at low water. Menunketesuck Point is composed entirely of glacial till containing a large proportion of great boulders. To these it owes its continued existence, but the broad fringe of boulders surrounding the point indicate that it has suffered a large amount of erosion in the past, when the fine material mixed with the boulders was washed away leaving the latter as evidence of the former greater extension of the till mass. At present the Point is scarcely 100 feet (Plate V, a) wide, but it is evident from the overhanging cliffs of bare till that it will grow much smaller and eventually disappear leaving for a time a bouldery shoal to mark its location. Such shoals are fairly common in the Sound; and many of them undoubtedly mark the sites of former islands of glacial material.

Beach drifting, a process explained in Chapter II, in a westward direction from Westbrook to Menunketesuck Point is indi-

cated by the growth of the bar from the mainland toward the Point, but west of Menunketesuck the movement of drift is in the opposite direction as indicated by the accumulation of sand on the western side of groins and the eastward growth of the bar attached to the mainland at Grove Beach and extending toward the Point. These two bars stretching outward toward Menunketesuck Point are shown on Coast Survey Chart No 216, and in spite of the break at their apex, where the inlet of the Patchogue River is situated, form a good example of a cuspate bar. Bars of this type in all stages of development are common on the Connecticut coast. In many cases the islands, to which they originally extended, have been entirely destroyed leaving only a rocky shoal connected to the shore by a submarine bar. Johnson[1] has described such a cuspate bar in Fairfield, where the Cows, a number of offshore rocks tied to the mainland by Fairfield Bar, probably represent a former island once similar in situation to Menunketesuck Point. Further erosion ending in the destruction of the latter will result in a feature very like that now seen at Fairfield.

STORM DAMAGE NEAR HAMMOCK POINT.

From a short distance east of Kelsey Point nearly to Hammock Point very expensive structures defend the shore, although Hammock Point, composed of till, is unprotected and shows evidences of great erosion. Mr. Burton Wright of Worcester, Mass., kindly furnished the author with the following notes concerning erosion on this short stretch of coast: all protective works erected prior to the present costly seawalls have been destroyed, and in places it has been necessary to move cottages back 60 feet to avoid crumbling walls. The shore in front of the Wright cottage has retreated 50 feet averaging a foot a year before the construction of the latest defenses. Local tradition says that ox teams were often driven out to Stone Island before the breakwater was built. Now, however, a swimmer cannot make headway against the sweep of the tidal current between Stone Island and the mainland, and the channel is eight feet deep. Owners of local shorefront property are convinced that the rapid erosion is due to these tidal currents caused by the building of a breakwater, which extends from Stone Island about two-thirds of a mile out to sea and restricts the currents to a narrow channel between the island and the shore. Their sad experiences with cheaply-constructed protective works have taught them the futility of building anything but the heaviest and most expensive structures, such as their last seawalls. Anything else is false economy.

[1]Johnson, D. W., "The New England-Acadian Shoreline," pp. 438-441.

HAMMONASSET BEACH.

In Hammonasset Beach in Madison the people of Connecticut own one of the longest and most beautiful stretches of sand beach in their State. As mentioned in Chapter I they have in this a self-supporting State Park maintained and operated for their benefit, and the writer strongly urges every resident or visitor in Connecticut who may not have beach privileges elsewhere, to visit and enjoy the excellent beach available here. The outer two-thirds toward Hammonasset Point is a tombolo uniting the Point to the mainland. The former stands about 20 feet above sealevel and is composed of till containing many huge boulders, which form the shore as far as West Rock in Clinton Harbor. Offshore boulders and shoals testify to the former greater extent of the till, which, before the building of the tombolo and the deposition of the marsh, must have appeared as an island at a considerable distance from the mainland. At low tide the surface of the beach averages 100 feet in width and slopes seaward about seven degrees. Behind the beach is usually found an area of dune sand of considerable width but little height. These dunes have been breached in a number of places on the western side of the Beach, and material has been carried three or four hundred feet back over the marsh. These breaks usually take place during winter storms at which times the marsh and low upland on which the park buildings stand may be partly inundated.

THE MADISON SHORELINE.

The remaining shore of Madison shows no features of great interest. As a rule it is composed of the stratified sands and gravels of a low plain, which has suffered severe erosion, although the larger part is now protected by seawalls. Shorefront acreage is extremely valuable here, and the shore defenses are proportionately expensive. Immediately west of Hammonasset Beach the rapid wasting of the shore has caused the abandonment of a road, and the caving banks indicate the source of much material for that Beach. The shoreline in glacial material is occasionally interspersed with a brief stretch of bedrock, which invariably makes a slight projection and can be regarded as a contraposed shoreline. Tuxis Island and Gull Rock are rock islands, which were probably at one time largely or entirely covered by loose material. According to Mrs. Wilson Coe of Madison, Gull Rock was formerly tied to the mainland by a tombolo on which grew beach plums, while Tuxis Island could be reached by stepping from stone to stone at low tide. The upland here is said to have retreated at the rate of a foot a year before strenuous efforts at protection were made. At Hogshead Point the upland ends, and the shorefront is formed by a low bar of sand lying before the

extensive East River marshes. In many places considerable areas of marsh appear outside the cordon of sand showing the retreat of the latter over the marsh surface. The end of this bar at East River shows two minor recurved hooks extending out into the marsh and denoting the former position of the shoreline, when the drift of material was more directly northward.

The Shoreline Between East River, Guilford, and New Haven Harbor.

The fourth district into which the shoreline may be divided is that lying between East River and New Haven Harbor and shown in Fig. 27. More than any other part of the coast it is a shoreline of hard rock, and in contrast to the districts on either side, its irregularity is very great and is a distinguishing characteristic of shorelines formed of resistant rock. This is Connecticut's rockbound coast. Banks and cliffs eroded in glacial material are almost unknown. Beaches are comparatively rare and small, and in common with the few other depositional forms deserve notice only because of their importance as centers for beach colonies. The larger number of beaches are of the pocket type in which a short stretch of sand is embraced between two projecting points of rock. Short Beach in Branford is an example of this type, and the bars at the head of Joshua Cove (Great Harbor) and Little Harbor (Shell Beach) in Guilford may likewise be considered pocket beaches. In Joshua Cove a narrow tombolo (Plate V, b) submerged at high tide, connects the eastern island of rock to the middle of the beach before the marsh.

CHANGES IN GREAT AND LITTLE HARBORS.

The marsh area behind the Little Harbor bar is drained by an unusually circuitous stream flowing first northeastward, then southeastward, and finally southwestward through the tidegate in the dike on the Joshua Cove bar. The natural course for the drainage of this marsh would be by the short route through the Little Harbor bar, and it formerly passed through an outlet there, which was closed by a storm forcing the marsh to drain into Joshua Cove. More recently a new outlet has been dug through Little Harbor bar in connection with mosquito elimination work, but this has been filled by sand several times during storms necessitating reexcavation. The bar at the head of Joshua Cove has been driven back over the marsh for a considerable distance as is indicated by the broad expanse of severely eroded marsh peat lying exposed to the waves in front of the bar. Local residents state that this retreat has been 50 feet within their memory, and the evidence corroborates them in indicating an unusually rapid

retreat for a bar located at the head of a bay. At present the bar is resting against a dike which was formerly the embankment of an electric railroad, and it appears that this should retard further retreat to a considerable extent. Nevertheless it is reported that the debris from this erosion has spread over the flats near the head of the Cove in sufficient quantities to impair their value as clam beds. (See Plate IV, b.)

DOUBLE BEACH TOMBOLO.

Double Beach (Plate VI, a) in Branford Harbor is a well known though small example of a tombolo. It connects Lovers Island to the mainland and has long been a popular picnic and beach resort. The largest bars of the district are those stretching from South End to Morgan Point to Lighthouse Point just outside New Haven Harbor. As shown in Plate VI, b, these bars through the action of the wind have attained considerable width and elevation being capped by sand dunes, which are semi-fixed by vegetation.

WIND ACTION ON BEACHES.

Many other bars of the Connecticut coast show a similar capping of dune sand, by which their tops are elevated several feet above storm high tide level. Waves alone are unable to build a bar higher than they themselves can reach, but with the help of a favorable wind bars can be reared to much greater heights. The direction of the wind is very important. If it blows offshore strongly and often enough to cause a predominant movement of sand in that direction, the bar will probably never attain an elevation above the reach of the highest storm waves and may be much lower. Much of the sand brought in by the waves will be carried out to sea again and will not be permanently added to the beach. On the other hand, if onshore winds are more important, the height and width of the bar may both be increased by wind deposits. As soon as the waves have built the bar high enough to allow some of the sand to become dry at low tide, the wind will carry the dry sand higher and depositing it build the upper part of the beach considerably above the reach of the waves at high tide. Some of the sand may be carried down the backslope of the beach and deposited on the edge of the lagoon or marsh gradually adding to the width of the bar, so that it may be growing wider in one direction by the work of the waves and in the other through the aid of the wind. The best example of wind work on the Connecticut coast is to be seen on the long wide bar leading from the east out toward Menunketesuck Point.

Shoreline from New Haven Harbor to the Norwalk River.

The fifth district includes the shoreline from New Haven Harbor west to the Norwalk River and is shown in Figs. 28 and 29. It differs markedly from the district immediately to the east lacking almost entirely the irregularity lent to the latter by the many outcrops. The few ledges which occur at the shore are practically confined within a four-mile stretch lying between Savin Rock and Pond Point in the eastern end of the district. The rock is phyllite and schist, less resistant than the granite gneiss outcropping east of New Haven, but as already stated responsible for the slight irregularities of Savin Rock, Oyster River Point, and Merwin Point (Plate II, a and b). The alternation of drift and phyllite at Merwin Point has resulted in a scalloped shoreline with the indentations cut in the drift and the projections formed of phyllite. It appears probable that the phyllite outcrops were at one time entirely hidden by drift and were exposed by wave erosion, in which case this is another small example of a contraposed shoreline.

THICKLY POPULATED SHORELINE.

From end to end the shorefront of this district is probably more closely populated by summer visitors than any other section of the Connecticut coast. This is especially true of that part lying between New Haven Harbor and the Housatonic River, where the last short stretch of unoccupied shore is being developed at the present time. The shores of Milford and Orange are literally lined with summer cottages of various degrees of pretension. Taxes on many of these properties are paid to Long Island Sound as well as to the local governments, for the general movement of the shoreline seems to be retreat, sooner or later involving the pocketbook of every waterfront owner. Money for protection has been expended upon most of this shoreline, but the structures built have been so weak that as a rule erosion has not been stopped, and the waste continues. Many land owners have not learned that it is cheaper in the end to build a strong wall, which will form an efficient protection for years, rather than a weak one, which is not only partially destroyed by the storms of each winter, but in addition allows the waves to damage their upland, requiring an annual expenditure for repair and rebuilding.

RESTORATION OF SHORELINE FROM NEW HAVEN TO BRIDGEPORT HARBORS.

The unconsolidated deposits of which this shore is largely composed have been favorable for the development of many erosional and depositional features, so that the coastal outline has been

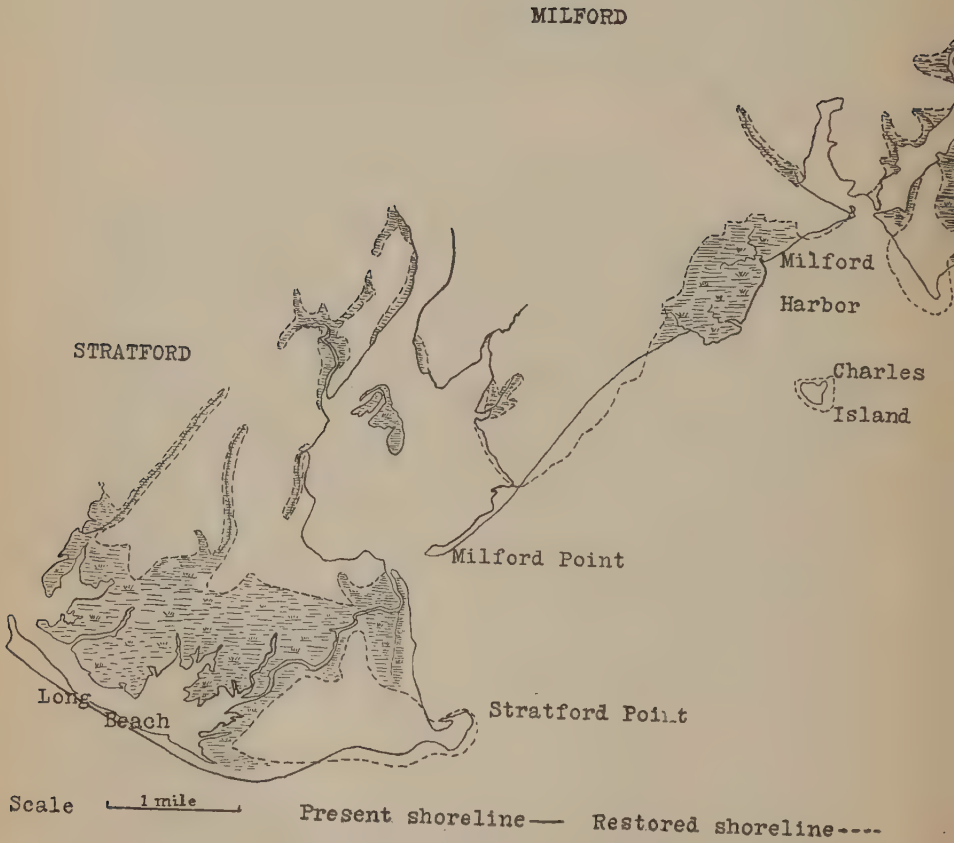
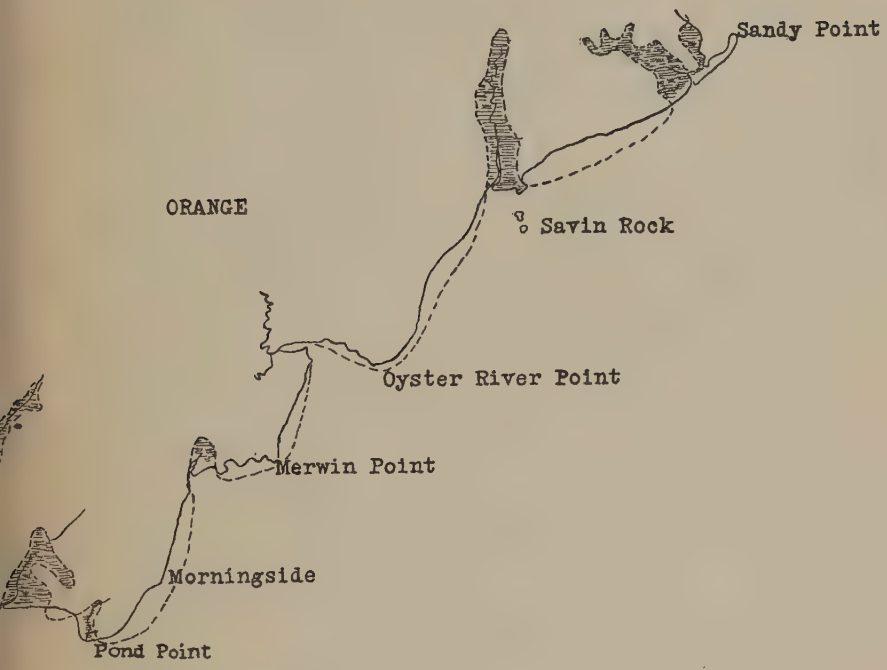


Fig. 28. Outline map showing restoration o



horeline from New Haven to Bridgeport Harbors.

changed greatly from its original shape. Contrasted with the third district, the shoreline of which is composed chiefly of low-lying stratified material, this district possesses a number of till cliffs reaching a maximum height of 40 feet. While these need not indicate any greater retreat of the shore than a three-foot cliff eroded in a gently sloping outwash plain, they are more impressive evidences of erosion, and make this district an interesting one in which to attempt a restoration of the pre-modification coastal outline. Its close settlement may also attract the interest of a larger number of people to such a restoration, of which the map shown in Fig. 28, covers that part of the district lying between New Haven and Bridgeport including the shores of the towns of Orange, Milford, and Stratford.

Such a reconstruction requires three processes. Two of these are quite simple and often produce very noticeable changes in the shoreline, while the third is more difficult and often entails such slight alterations that they scarcely show on a map with a scale of one inch to the mile. The first operation is the removal of all the areas of salt marsh, for these developed subsequent to the initial outline of the shore as formed by submergence. This can be done directly from the map, and as a rule requires no checking in the field. The second step is the erasure of all depositional features, for they have developed as a result of erosion of the initial shoreline, and hence are later modifications of it. This can usually be accomplished by map study to some extent, but often requires checking in the field to determine the exact point where the upland ends and the wave-built form begins. When the marshes and depositional features have been removed, and lines drawn to show the location of the new shoreline, the latter will, on the Connecticut coast, usually prove to be practically in its final state with the changes to be made by the third process relatively unimportant. Thus far the reconstruction has resulted in the curtailment of the land area, but the third process, which is the determination of the former position of the eroded shoreline of the upland, will add to the area of the land.

The location of the pre-erosion shoreline of an area, the shore of which now stands in cliffs from 1 to 40 feet in height, demands field study. Even then, the personal factor enters so largely into the problem that it would be difficult to get two observers to agree exactly upon the amount of retreat of the shore at any given point. This is especially the case, where erosion is measured in miles, but it holds true on the Connecticut coast line, where it is measured in hundreds of feet. For the area in which the reconstruction has been undertaken, the erosional changes are too small to seem impressive on the map (Fig. 28), where a retreat of more than 500 feet can be represented by one-tenth of an inch. In the field, nevertheless, such a retreat may cut backward far enough into

the upland to form high and overhanging cliffs, which are noteworthy features of the shoreline.

HIGHEST CLIFFS OF DRIFT ON THE COAST.

Between New Haven and Bridgeport occur the highest cliffs in unconsolidated material to be found on the Connecticut coast; the highest of these (Plate VII, a) is to be seen northeast of Pond Point along Morningside, where a vegetation-covered cliff eroded in till reaches a height of 40 feet. This cliff continues southward with diminishing altitudes nearly to Pond Point, and in a number of places shows signs of slumping and erosion, which have caused trouble for the upland owners. In the vicinity of the higher part of the cliff the shoreline seems to have retreated 500 feet with progressively smaller amounts of retreat north and south of this point as indicated in Fig. 28. Similar cliffs in till reaching a height of nearly 40 feet are also found a short distance west of the Stratford Point Light, where the sea is actively attacking the upland, here greatly exposed. In a reentrant of the shore a short distance further west a low grass and brush covered sand flat (Plate VII, b) is situated before an abandoned cliff, which reaches a height of 15 to 20 feet. Originally the upland here must have extended outward somewhat beyond the present shoreline, but it was cut away during a regime of erosion, which was succeeded by deposition prograding the shore to the extent of the three or four hundred foot wide sand flat. Abandoned seacliffs at present sealevel occur commonly along the shore and are usually situated at the rear of a salt marsh. In such locations they seem to have originated through erosion by waves from the open Sound before the building of a bar allowed the growth of marsh material within the protection of the lagoon. Probably the waves within the usually narrow lagoons have little influence in cliff cutting. Another excellent example of an abandoned seacliff (Plate VIII, a) is seen in Milford on the Welch Point Road south of Oldfield Lane, where the highway climbs directly up the face of the cliff in a sudden sharp rise of 15 feet above the level of the Milford Public Beach. The 20-foot contour follows this cliff for a short distance, where it runs directly north and south, and residents on the upland descend to the Beach by a series of steps. The southern end of this abandoned cliff is abruptly terminated by its intersection with the freshly eroding embankment running along the southwestern shore of Welch Point. The old cliff was probably formed at a time, when its southward continuation passed seaward of the present fresh cliff in a gently rounded curve gradually swinging back toward Welch Point. The entire upland of Welch Point is composed of till containing many large boulders; the cliff on the southwestern side facing Charles Island

reaches an elevation of 40 feet, and as indicated in Fig. 28 has probably been formed by a retreat of the upland shore amounting to 500 feet.

CHARLES ISLAND TOMBOLO.

The Charles Island tombolo is the one thing of interest on the almost featureless shore between Milford and Milford Point. Charles Island is composed of till bordered on each side by 10-foot cliffs and is said to contain 12 acres of land. Although until recently long unoccupied, it is now being prepared for occupation by a church brotherhood, which, it can be predicted, will need to spend a considerable sum on shore protection. At high tide it seemingly stands in the midst of the sea a half mile from shore, but as the tide ebbs a long line of whitecaps can be seen breaking over a submerged bar along which venturesome figures cautiously pick their way toward the Island. One standing on it at this stage indeed feels that he is surrounded by water and far from shore; gradually a narrow ridge of sand and stone appears above the waves and the clammer walks outward on a path (Plate VIII, b), which resembles one of the old turnpiked roads. Now the tombolo shows at its prettiest, and the Island is seen to be truly tied to the mainland by a bar. At low tide, however, a broad area of sand and mud is exposed, and the observer would scarcely think of it as tombolo, had he not seen it at a different level of the water. At midtide it is the best example of a tombolo to be seen in Connecticut. It is well represented on Coast Survey Chart No. 219, but naturally does not show on the Bridgeport topographic sheet of the United States Geological Survey, since the latter does not map submarine features. The base of the tombolo joins the apex of a cuspate foreland, of which the western arm is better developed than indicated by the maps, and as suggested by Johnson[1] the tombolo and the foreland together form a Y-tombolo deriving material for its sustenance from the wasting of the Island and the mainland in both directions.

LARGE SPITS.

Three spits of note occur within the area for which reconstruction has been attempted. In order from east to west they are Sandy Point in New Haven Harbor, Milford Point extending westward toward the mouth of the Housatonic, and the low narrow bar of Long Beach terminating in Pleasure Beach and encircling the extensive Stratford marshes. As these in common with all the other depositional features have been built since the original shoreline of submergence was formed, they are removed

[1]Johnson, D. W., "The New England-Acadian Shoreline, p.' 439.,

from the restoration (Fig. 28) representing the initial coastal outline.

FAIRFIELD-STRATFORD PLAIN.

A strip, eight miles long, averaging a mile in width, and bordering the Sound in Stratford, Bridgeport, and Fairfield differs very markedly in its topography from the remaining parts of these towns. Viewed from an elevation it is seen to be a low and level area, which as pointed out to the author by Professor R. F. Flint of Yale, greatly resembles an undissected coastal plain. It is composed of stratified sand and gravel with infrequent inconspicuous outcrops of bedrock, and at the north is terminated abruptly by the hills of the crstalline upland. It forms the largest area of flat land along the shore of the State being wider than the low coastal strips in the towns of Madison, Clinton, and Old Lyme, but it resembles these and probably originated in the same way as deposits of streams from the melting of a glacier. The shore of the larger part of this flat area consists of low and narrow bars, such as are seen at Long and Fairfield Beaches. These narrow bars are cut and filled very rapidly by the waves, and often change their shape greatly within a few years. An example of this is seen at Pine Creek Point, where the addition of sand to the end of the outer bar has caused the inlet to move about one-third of a mile west of the position it occupied at the time the Norwalk sheet was mapped. At present the bar reaches to the tip of the drumlinoid hill east of Southport. If the map was correctly drawn, this is a change of about 1600 feet in 38 years, or an average growth of about 42 feet per year. It does not seem probable that the present inlet will continue to be pushed further west, however, since the bar between it and Pine Creek Point is so low and narrow that it will surely be breached during some heavy storm with the consequent formation of a new inlet at the break and the probable closing of the old one.

Few features of note occur west of Kensie Point, although bedrock is found outcropping at the shore again for the first time in many miles. Johnson has figured and briefly mentioned[1] the cuspate forelands of Shoal, Pine Creek, and Cedar Points in this part of the district. Several high hills occurring near the shore are worthy of comment, although they have no effect upon the coastal configuration. They are in order from east to west the ovate Grover Hill in Bridgeport, the elongate hill ending in Kensie Point in Fairfield, and the somewhat circular Compo Hill in Westport. Surficially they are composed of drift, although a few outcrops of crystalline rock occur on Compo Hill, and it seems likely that it lies near the surface on the other two.

[1]Johnson, D. W., "The New England-Acadian Shoreline," pp. 439-441.

Shoreline from Norwalk River to New York State Line

The sixth district (Fig. 29) of the shoreline extends from the Norwalk River to the New York State line, and as far as the unity of its physical characteristics is concerned might well be extended to New York City. In contrast to the preceding district it has a shoreline which may be fairly said to gain its dominant traits from the occurrence of many outcrops of hard rock at the water's edge. It is therefore much more irregular than the district, the description of which has just been concluded, and is more lacking in depositional and erosional features. Located well within the area influenced by the nearness of the metropolis, the shorefront is practically all occupied, although the small homes and cottages of vacationists are no longer so prominent, being replaced in many instances by palatial residences and large estates. These are usually posted and guarded against trespassers, so that even with a letter of introduction the geologist studying the area is likely to suffer many interruptions.

NORWALK ISLANDS.

The most interesting feature of this district is the group of Norwalk Islands lying from one to two miles off the mouth of the Norwalk River. Although represented on the Norwalk topographic sheet of the United States Geological Survey, they are best studied on the U. S. Coast and Geodetic Survey Chart No. 221 in which the submarine shoals and rocks are indicated. They are a remarkable group of eroding islets composed of glacial debris and range up to one mile in length and one-third of a mile in width. In only two or three cases do they reach a height of 20 feet, and every hill that reaches this elevation has apparently been more than half removed by waves. All have suffered extensive erosion, and many boulder shoals undoubtedly mark the location of former islands of boulder till, which have completely disappeared. Material derived from their wasting has sufficed to build numerous beaches, bars, and spits, such as are seen around Cockenoe, Chimon, and Sheffield Islands, the larger members of the group. The orientation and composition of the Norwalk Islands makes it seem probable that they are formed of terminal moraine deposits of the glacier, while its front remained stationary for a time during its recession. They are thus similar in origin to Fishers Island and its associated shoals, which were formed at the time the ice was depositing the earlier Harbor Hill moraine.

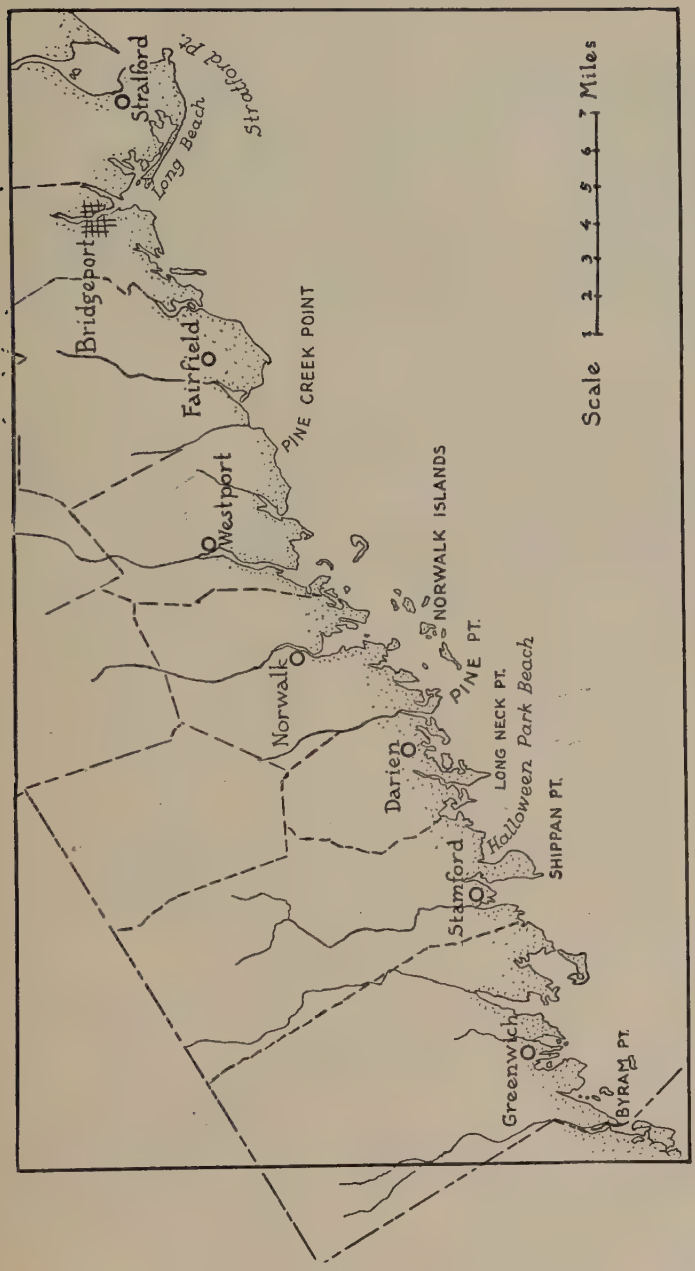


Fig. 29. Outline map of the shoreline from Bridgeport Harbor to the New York Statee line.

LONG NECK AND SHIPPAN POINTS.

Between Norwalk and Stamford, Long Neck and Shippan Points are the only shoreline features, which do not owe their shape mainly to the outcropping of hard rock at the water's edge. These two points as their regular outlines indicate, are at least composed of glacial drift surficially, although bedrock outcrops in a few places on Long Neck Point. Shippan Point was formerly built out in a cuspate foreland[1] but subsequent artificial filling has altered this feature beyond recognition in the field or on the maps. The southeastern shore of the Point is composed of very large boulders seeming to indicate that the hill contains a thick cover of till.

HALLOWEEN PARK BEACH.

The city of Stamford has spent a large amount of money in developing bathing facilities at Halloween Park on the shore of Westcott Cove. In the past the results have been unsatisfactory, but recent construction seems more promising and may yield a permanently good beach except for slight replacement of material when necessary. In 1910 the area, a salt marsh, was covered by a sand fill, and in 1921 an expensive bathing pavilion was erected. Since then it is said that the shore has retreated as much as 15 feet a year endangering the pavilion and undermining a road; at the time of the author's first visit fallen lamp posts and exposed conduits testified to the power of the waves. Most of the material removed from the front of the pavilion drifted westward without hindrance, since three inadequate timber groins at the western end of the beach had been destroyed, and was finally deposited in an inlet, which has been gradually closed. A long stone jetty extending outward from a point just east of the mouth of the inlet will probably catch the sand, which has heretofore blocked the channel, but it will doubtlessly be advisable to construct a series of groins along the rest of the beach to stop erosion such as has occurred in the past.

From Stamford to the end of the district the shore is composed of alternate stretches of crystalline rock and drift with the characteristics of a crystalline shoreline somewhat more prominent. Greenwich Point is the most noticeable feature of glacial origin and presents the typical even mature shoreline of most forms composed of unconsolidated material. Depositional features are not as common as in districts largely composed of unconsolidated materials, but there is no lack of good bathing beaches, frequently of the pocket beach type, where the sand is held within the projections of two rock points.

[1]Johnson, D. W., "The New England-Acadian Shoreline," p. 242.

Summary.

Most of the Connecticut shoreline is composed of unconsolidated material of glacial and fluvioglacial origin. This material is eroded easily even by the comparatively small waves of Long Island Sound, and for that reason most of the shoreline has suffered and is suffering damage due to the attack of the sea. In his survey of the shoreline from end to end of the state nothing impressed the author more than the very evident fact that almost every shorefront owner, where the coast was not composed of rock, was paying taxes to the Sound either in the form of lost land or costly shore protection. This will continue, for when the waves erode even the hardest rock, man cannot hope to defeat their attack completely. Nevertheless by the building of types of shore protective devices shown by long experience to be successful, erosion can be practically stopped. Cheaply and carelessly erected groins and seawalls will rarely prove satisfactory and may hasten the very erosion they are supposed to retard. The author has seen many cases where weak protective works have been destroyed, and the landowner has been compelled to go to the expense and trouble of building stronger protection. When once it is decided to build shore protection, build carefully and strongly.

a. View of Forbes Bluffs, cliffs of trap, washed by the waves of New Haven Harbor.

b. Another view of the same Bluffs.

PLATE I

a. Savin Rock, showing nip at high tide level.

b. Phyllite outcrop forming shore at Merwin Point.

a. Uncliffed headland in an exposed position on Sachem Head (Photograph by U. S. G. S.).

b. Joint shoreline at Joshua Cove.

a. House at Saybrook Manor beach left on piles on retreat of shoreline.

b. Scene at the head of Joshua Cove (Great Harbor) showing badly eroded peat exposed by the retreat of the sand bar over the marsh (Photograph by Cohen).

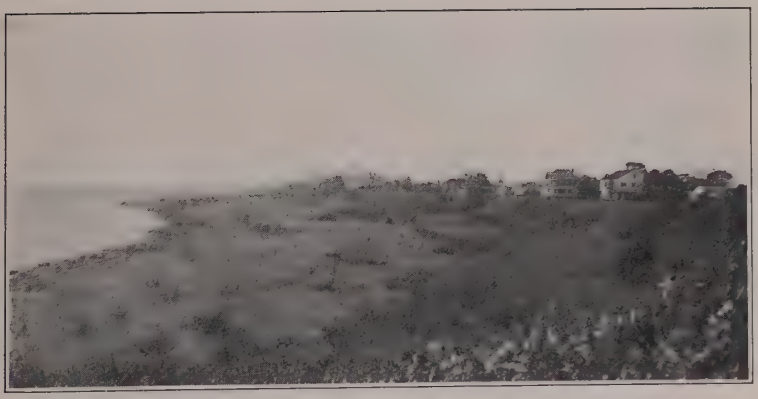
a. Menunketesuck Point, a till island, showing signs of great erosion.

b. Tombolo in Joshua Cove: note slope of the upland.

a. Double Beach, a tombolo, in Branford Harbor (Photograph by Gianella).

b. Bar capped by dunes, Morgan Point, East Haven (Photograph by U. S. G. S.).

a. Vegetation-covered cliff in till near Pond Point, Milford.



b. Prograded shoreline west of Stratford Point Light.

a. Abandoned seacliff on Welch Point Road, Milford.

b. Charles Island tombolo, Milford, looking north (Photograph by A. S. G. S.).

BULLETINS

OF THE

State Geological and Natural History Survey of Connecticut

1. First Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1903-1904; 18 pp., 23 cm., 1904.

2. A Preliminary Report on the Protozoa of the Fresh Waters of Connecticut: by Herbert William Conn, Ph.D.; 69 pp., 34 pls., 23 cm., 1905. *(Out of print as a separate bulletin. To be obtained only in Vol. I, containing Bulletins 1-5. Price $1.75 postpaid.)*

3. A Preliminary Report on the Hymeniales of Connecticut: by Edward Albert White, B.S.; 81 pp., 40 pls., 23 cm., 1905. *(Out of print as a separate bulletin. To be obtained only in Vol. I, containing Bulletins 1-5. Price $1.75 postpaid.)*

4. The Clays and Clay Industries of Connecticut: by Gerald Francis Loughlin, S.B.; 121 pp., 13 pls., 23 cm., 1905.

5. The Ustilagineae, Smuts of Connecticut: by George Perkins Clinton, S.D., 45 pp., 55 figs., 23 cm., 1905.

6. Manual of the Geology of Connecticut: by William North Rice, Ph.D., LL.D., and Herbert Ernest Gregory, Ph.D.; 273 pp., 31 pls., 22 figs., (10 maps) 23 cm., 1906. *(Out of print as a separate bulletin. To be obtained only in Vol. II, containing Bulletins 6-12. Price $2.75 postpaid.)*

7. Preliminary Geological Map of Connecticut: by Herbert Ernest Gregory, Ph.D., and Henry Hollister Robinson, Ph. D.; 39 pp., 2 maps (1 in pocket), 23 cm., 1907.

8. Bibliography of Connecticut Geology: by Herbert Ernest Gregory, Ph.D., 123 pp., 23 cm., 1907.

9. Second Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1905-1906; 23 pp., 23 cm., 1906.

10. A Preliminary Report on the Algae of the Fresh Waters of Connecticut: by Herbert William Conn, Ph.D., and Lucia Washburn (Hazen) Webster, M.S.; 78 pp., 44 pls., 23 cm., 1908.

11. The Bryophytes of Connecticut: by Alexander William Evans, Ph.D., and George Elwood Nichols, B.A.; 203 pp., 23 cm., 1908.

12. Third Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1907-1908; 30 pp., 23 cm., 1908.

13. The Lithology of Connecticut; by Joseph Barrell, Ph.D., and Gerald Francis Loughlin, Ph.D.; 207 pp., 6 tables, 23 cm., 1910.

14. Catalogue of the Flowering Plants and Ferns of Connecticut growing without cultivation: by a Committee of the Connecticut Botanical Society consisting of Charles Burr Graves, A.B., M.D., Edwin Hubert Eames, M.D., Charles Humphrey Bissell, Luman Andrews, Edgar Burton Harger, Ph.B., and Charles Alfred Weatherby, A.M.; 569 pp., 23 cm., 1910.

15. Second Report on the Hymeniales of Connecticut: by Edward Albert White, B.S.; 70 pp., 28 pls., 23 cm., 1910.

16. Guide to the Insects of Connecticut: prepared under the direction of Wilton Everett Britton, Ph.D. Part I. General Introduction: by Wilton Everett Britton, Ph.D. Part II. The Euplexoptera and Orthoptera of Connecticut: by Benjamin Hovey Walden, B.Agr.; 169 pp., 11 pls., 16 figs., (1 map), 23 cm., 1911.

17. Fourth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1909-10; 31 pp., 23 cm., 1910.

18. Triassic Fishes of Connecticut: by Charles Rochester Eastman, Ph.D.; 78 pp., 11 pls., 8 figs., 23 cm., 1911.

19. Echinoderms of Connecticut: by Wesley Roswell Coe, Ph.D.; 152 pp., 32 pls., 29 figs., 23 cm., 1912.

20. The Birds of Connecticut: by John Hall Sage, M.S., and Louis Bennett Bishop, M.D., assisted by Walter Parks Bliss, M.A.; 370 pp., 23 cm., 1913.

21. Fifth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1911-1912; 27 pp., 23 cm., 1912.

22. Guide to the Insects of Connecticut: prepared under the direction of Wilton Everett Britton, Ph.D. Part III. The Hymenoptera, or Wasp-like Insects, of Connecticut; by Henry Lorenz Viereck, with the collaboration of Alexander Dyer MacGillivray, Ph.D., Charles Thomas Brues, M.S., William Morton Wheeler, Ph.D., and Sievert Allen Rohwer; 824 pp., 10 pls., 15 figs., 23 cm., 1916.

23. Central Connecticut in the Geologic Past: by Joseph Barrell, Ph.D.; 44 pp., 5 pls., 23 cm., 1915.

24. Triassic Life of the Connecticut Valley: by Richard Swann Lull, Ph.D., 285 pp., 3 maps, 12 pls., 126 figs., 23 cm., 1915.

25. Sixth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1913-1914; 24 pp., 23 cm., 1915.

26. The Arthrostraca of Connecticut: by Beverly Waugh Kunkel, Ph.D.; 261 pp., 84 figs., 23 cm., 1918.

27. Seventh Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1915-1916; 17 pp., 23 cm., 1917.

28. Eighth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1917-1918; 21 pp., 23 cm., 1919.

29. The Quaternary Geology of the New Haven Region, Connecticut: by Freeman Ward, Ph.D.; 80 pp., 9 pls., 17 figs., 23 cm., 1920.

30. Drainage Modifications, and Glaciation in the Danbury Region, Connecticut: by Ruth Sawyer Harvey, Ph.D.; 59 pp., 5 pls., 10 figs., 23 cm., 1920.

31. Check List of the Insects of Connecticut: by Wilton Everett Britton, Ph.D.; 397 pp., 23 cm., 1920.

32. Ninth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1919-1920; 18 pp., 23 cm., 1920.

33. Geology of the Stonington Region, Connecticut: by Laura Hatch Martin, Ph.D.; 70 pp., 1 map, 8 figs., 23 cm., 1925.

34. Guide to the Insects of Connecticut: prepared under the direction of Wilton Everett Britton, Ph.D. Part IV. The Hemiptera or Sucking Insects of Connecticut: by Wilton Everett Britton, Ph.D., with collaboration of James Francis Abbott, Ph.D., Arthur Challen Baker, Ph.D., Harry Gardner Barber, A.M., William Thompson Davis, Dwight Moore DeLong, Ph.D., William Delbert Funkhouser, Ph.D., Harry Hazelton Knight, Ph.D., Asa Chandler Maxson, Herbert Osborn, D.Sc., Howard Madison Parshley, Sc.D., Edith Marion Patch, Ph.D., Louis Agassiz Stearns, M.Sc., José Rollin de la Torre-Bueno, F.E.S., Edward Payson Van Duzee, Harley Frost Wilson, M.S.; 807 pp., 20 pls., 169 figs., 23 cm., 1923.

35. Tenth and Eleventh Biennial Reports of the Commissioners of the State Geological and Natural History Survey, 1921-1924; 17 pp., 23 cm., 1924.

36. The Uredinales or Rusts of Connecticut and Other New England States: by Willis Roberts Hunt, Ph.D.; 198 pp., 2 figs., 23 cm., 1926.

37. Catalogue of the Lichens of Connecticut: by Alexander William Evans, Ph.D., and Rose Meyrowitz, M.S.; 56 pp., 23 cm., 1926.

38. Twelfth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1925-1926; 23 pp., 1 pl., 23 cm., 1927.

39. The Odonata or Dragonflies of Connecticut: by Philip Garman, Ph.D.; 331 pp., 22 pls., 67 figs., 23 cm., 1927.

40. The Geology of the Shepaug Aqueduct Tunnel, Litchfield County, Connecticut: by William Macdonough Agar, Ph.D., with a chapter by Robert A. Cairns; 38 pp., 8 pls., 2 maps, 3 figs., 23 cm., 1927.

41. Guide to the Geology of Middletown, Connecticut, and Vicinity: by William North Rice, Ph.D., LL.D., and Wilbur Garland Foye, Ph.D.; 137 pp., 3 pls., 33 figs., 23 cm., 1927.

42. The Algae of Connecticut; by Clarence John Hylander, Ph.D.; 245 pp., 28 pls., 23 cm., 1928.

43. The Life Forms of Connecticut Plants and Their Significance in Relation to Climate; by Beulah Ennis, Ph.D.; 100 pp., 20 pls., 23 cm., 1928.

44. Report on the Water Resources of Connecticut, by Roscoe Henry Suttie, C. E.; 168 pp., 7 figs., 23 cm., 1928.

45. Thirteenth Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1927-1928; 32 pp., 3 pls., 23 cm., 1929.

Bulletins 1, 9, 12, 17, 21, 25, 27, 28, 32, 35 and 38 are merely administrative reports containing no scientific matter. The other bulletins may be classified as follows:

Geology: Bulletins 4, 6, 7, 8, 13, 18, 23, 24, 29, 30, 33, 40, 41, 44.
Botany: Bulletins 3, 5, 10, 11, 14, 15, 36, 37, 42, 43.
Zoology: Bulletins 2, 16, 19, 20, 22, 26, 31, 34, 39.

These bulletins are sold and otherwise distributed by the State Librarian. Postage, when bulletins are sent by mail, is as follows:

No. 1	$0.05	No. 18	$0.10	No. 32	$0.05
3	.10	19	.10	33	.10
4	.10	20	.20	34	.25
5	.05	21	.05	35	.05
8	.05	22	.25	36	.10
9	.05	23	.05	37	.10
10	.10	24	.20	38	.05
11	.10	25	.05	39	.15
12	.05	26	.10	40	.05
13	.10	27	.05	41	.05
14	.20	28	.05	42	.10
15	.10	29	.10	43	.06
16	.10	30	.10	44	.10
17	.05	31	.20		

The prices when the bulletins are sold are as follows, postpaid:

No. 1	$0.10	No. 18	$0.30	No. 32	$0.10
3	.45	19	.50	33	.60
4	.35	20	.60	34	2.15
5	.20	21	.10	35	.10
8	.20	22	2.15	36	1.00
9	.10	23	.20	37	.60
10	.40	24	.70	38	.10
11	.35	25	.10	39	2.00
12	.10	26	.85	40	.50
13	.45	27	.10	41	1.00
14	.90	28	.10	42	1.50
15	.40	29	.60	43	.75
16	.40	30	.55	44	1.00
17	.10	31	1.60		

Limited numbers of these Bulletins have been assembled in volumes substantially bound in cloth, plainly lettered, and sell for the following prices, postpaid:

Volume I,	containing Bulletins 1-5	$1.75
Volume II,	containing Bulletins 6-12	2.75
Volume III,	containing Bulletins 13-15	2.75
Volume IV,	containing Bulletins 16-21	2.50
Volume V,	containing Bulletin 22	2.75
Volume VI,	containing Bulletins 23-32	4.15
Volume VII,	containing Bulletins 33-35	3.75
Volume VIII,	containing Bulletins 36-42	5.00

It is intended to follow a liberal policy in gratuitously distributing these publications to public libraries, colleges, and scientific institutions, and to scientific men, teachers, and others who require particular bulletins for their work, especially to those who are citizens of Connecticut.

Applications or inquiries should be addressed to

George S. Godard,

State Librarian,

Hartford, Conn.

In addition to the State Survey bulletins enumerated above, considerable work has been done by the State Survey in co-operation with the United States Geological Survey. The reports of such investigations have been published by the United States Geological Survey.

State Geological and Natural History Survey of Connecticut

COMMISSIONERS

JOHN H. TRUMBULL, *Governor of Connecticut*
JAMES ROWLAND ANGELL, *President of Yale University*
JAMES LUKENS MCCONAUGHY, *President of Wesleyan University*
REMSEN BRINCKERHOFF OGILBY, *President of Trinity College*
GEORGE ALLAN WORKS, *President of Connecticut Agricultural College*
IRENE NYE, *Acting President of Connecticut College for Women*

SUPERINTENDENT

W. E. BRITTON, Ph.D.
Agricultural Experiment Station, New Haven

DISTRIBUTION AND EXCHANGE AGENT

GEORGE S. GODARD, *State Library*
Hartford

CATALOGUE SLIPS

CONNECTICUT. *State Geological and natural history survey.*

Bulletin No. 46. The Physical History of the Connecticut Shoreline. By H. S. Sharp, Hartford, 1929.

97 pp., 8 pls., 28 figs., 23 cm.

SHARP, HENRY STAATS, 1902.

The Physical History of the Connecticut Shoreline, Hartford, 1929.

97 pp., 8 pls., 28 figs., 23 cm.

(Bulletin No. 46, Connecticut geological and natural history survey.)

GEOLOGY.

Sharp, H. S., The Physical History of the Connecticut Shoreline, Hartford, 1929.

97 pp., 8 pls., 28 figs., 23 cm.

(Bulletin No. 46, Connecticut geological and natural history survey.)

VITA

HENRY STAATS SHARP,
Born at Stuyvesant Falls, N. Y., March 26, 1902,
A.B. Cornell University 1924,
A.M. Columbia University 1926,
State Tuition Scholarship 1920-24,
Sigma Gamma Epsilon, Cornell 1924,
Sigma Xi, Columbia 1927,
Assistant in Geology, Cornell 1923-24,
Assistant in Geology, Columbia 1926-28,
Geologist Connecticut Geological Survey, 1927-28,
Lecturer in Geology, Columbia 1928-29,
Instructor in Geology, Columbia 1929.

PUBLICATIONS

"Karst Topography and Cavern Capture in Kentucky."

"The Drowned Meanders and Flood Plain Scrolls of Reelfoot Lake, Northwestern Tennessee." The Geographical Review, Vol. XVI, 1926, pp. 490-491.

"Storm Damage at Long Beach, N. Y.," Science n. s. Vol. LXV, 1927, pp. 257-258.

"Artificial Beach Construction in the Vicinity of New York," The Scientific Monthly, Vol. XXV, 1927, pp. 34-39.

"The Fall Zone Peneplane," Science, n. s. Vol. LXIX, pp. 544-545, 1929.